Continued Operation of the Massachusetts Alternative Septic System Test Center and the Investigation of Passive Nitrogen Removal Strategies for Onsite Septic Systems

(and Continued Operation of the Test Center to Investigate Proprietary Technologies)

Project 15-07 319

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Executive Summary

This project follows upon Project 14-03/319 and demonstrates the efficacy of non-proprietary strategies for the reduction of nitrogen from discharges of onsite septic systems with primary focus on soils-based treatment. Five full-scale systems were installed and tested at the Massachusetts Alternative Septic System Test Center and designed to receive 220 gallons per day, the equivalent of the full design capacity of a two-bedroom house in the Commonwealth of Massachusetts. The designs closely followed work done under the Florida Onsite Sewage Nitrogen Reduction Strategies (FOSNRS) Project[1] and work performed by others[2–4], with some modifications that anticipated regional and climate differences. All designs incorporated the use of lignocellulose or wood products (sawdust, mulch or woodchips) into the treatment process in a passive manner. Passive is defined by the fact that only one liquid pump is used. In all designs tested, this sole pump is used to distribute septic tank effluent to a low-pressure, time dosed Soil Treatment Area (STA aka. leachfield) comprised of 18 inches of sandy media to facilitate nitrification. Three designs position a layer of sandy media mixed in a ratio of 1:1 by volume with sawdust or wood mulch beneath the above-referenced nitrifying layer and maintain a saturated condition using an impervious liner (DESIGN 1,2 &3). One system conveys the nitrified percolate from the 18-inch depth of sand media to a box of woodchips (DESIGN 4). The final design underlays the nitrification layer with a 1:1 mixture (by volume) of sand and wood mulch in a free draining condition unrestricted by an impervious liner (DESIGN 5).

Generally, all designs achieve at least a 50% removal of nitrogen throughout the year, even in colder months. DESIGN 1,2,3 &5 exhibit clear seasonal trends and achieve levels Total Nitrogen (TN) levels less than 10 mg/L when temperature of the influent is above 10^{o}C. When temperatures are greater than 15^{o}C, percolate TN levels are often less than 5 mg/L TN which corresponds to greater than 85% removal. DESIGN 4, which diverts nitrified effluent to a container of woodchips exhibited an overall average TN of 3.6 mg/L (2.3 – 4.8 mg/L, $p= .05$) which reflects a 90% removal rate. This system was less affected by temperature. A major question relating to the longevity of carbon source that supports denitrification could not be anwered here, however literature reveiwed herein suggests that the longevity of saturated designs (1,2,3,4) would be expressed in decades. The unstaurated DESIGN 5, although appealing due to its simplicity and the fact that no final disposal area is required, requires further research to determine its longevity. Three of the systems (3,4 and 5) will continue to be the object of study from Stony Brook University, whose research efforts in the coming year will hopefully clarify some of these questions.

This project and Project 14-03/319 has encouraged significant interest by industry and non-proprietary researchers in using the principles demonstrated here and was the basis for securing a large demonstration grant from the Southeast New England Coastal Watershed Restoration Program of USEPA which is installing selected designs in summer 2017.

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Introduction

This report is a companion document with "Investigation of Passive Nitrogen Removal Strategies for Onsite Septic Systems at the Massachusetts Alternative Septic System Test Center (and Continued Operation of the Test Center to Investigate Proprietary Technologies) Project 14-01 319. The informational setting and definition of need is explained in that document. In summary, these two projects proceed from investigations of low-impact, sustainable and economical ways to treat wastewater for nitrogen in an onsite setting using non-proprietary means. In the Project 14-01/319, we endeavored to investigate the simplest means of interrupting the downward movement of percolate beneath a soil absorption system following the oxidation of ammonia (nitrification) with a source of carbon to promote denitrification. In that configuration, there is simply a layer of carbon (lignocellulose) mixed with sand or silty-sand positioned beneath the nitrifying strata of the system (figure 1). In the present study, we report on the use of a saturated layer of carbon:media mix located beneath the nitrification strata (figure 2), one additional unsaturated design, and an additional design diverting nitrified effluent to a box reactor of woodchips.

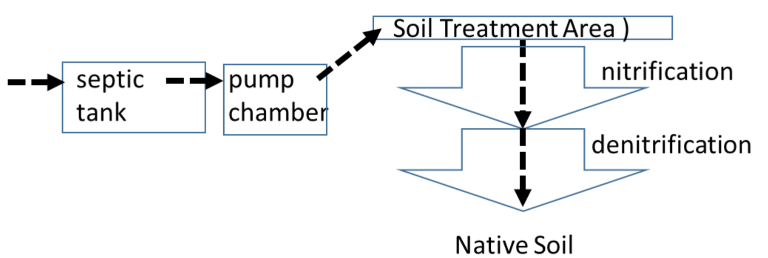


Figure 1. Schemata of "unsaturated" configuration that was the subject of PROJECT 14-01/319. Further experimentation with this method is also presented herein.

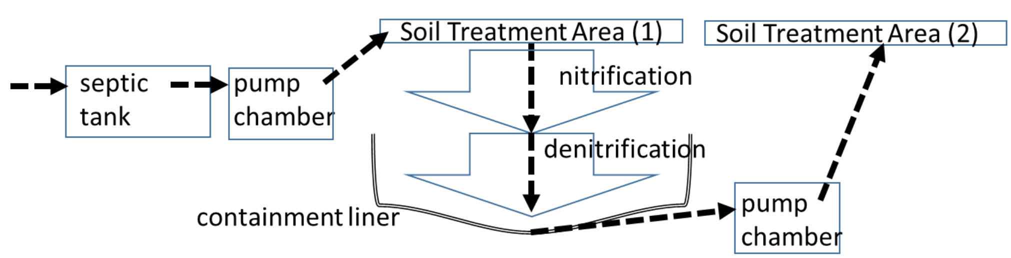


Figure 2. Diagrammatical representation of initial designs used under Florida Onsite Sewage Nitrogen Reduction Strategies (FOSNRS) studies.

The saturated designs copy closely those used in the Florida Onsite Sewage Nitrogen Reduction Strategies (FOSNRS) Project[1] with one exception. In the FOSNRS designs, a pump chamber is then required to deliver the final effluent to a second Soil Treatment Area (STA). We have omitted this portion of the design to focus on the denitrification treatment and to determine what further treatment (if any) would be required following exit from the lined portion of the system and prior to final disposal.

Project Description

This project reports on five full scale (220 gallon/day) systems using four concepts:

- DESIGN 1 - A saturated system started in December 2014 and operated until November 2016 (loamy sand as a nitrifying layer) (figure 3);
- DESIGN 2 - Operation of the above following replacement of the loamy sand with ASTM C33 Sand (sand that meets the requirements for standard fill under 310 CMR 15:255 – "Title 5" fill) (figure 4);
- DESIGN 3 - A saturated system as directly above installed with support from Stony Brook University and substituting "Long Island Sand" for the sand in both layers and "Long Island mulch" as a substitute for sawdust (figure 4 modified as described);
- DESIGN 4 -A nitrification layer underdrained and diverted to a box of woodchips (figure 5), and;
- DESIGN 5 - An unsaturated system similar in dimensions to the silty-sand – sawdust system reported in Project 14-01 319 but substituting sand and sawdust from Long Island, New York sources (figure 6).

Results

DESIGN 1- A saturated system started in December 2014 and operated until November 2016

This design follows closely designs used in the Florida Department of Health Onsite Nitrogen Reduction Strategies Study (FOSNRS) Stage 1 portion of a design. In that study, a drip dispersal system was used in conjunction with an 18-inch layer of sand for the nitrifying portion of the system and a nine-inch layer of a sawdust-sand mix was used for the underlying saturated denitrifying portion of the system. In the FOSNRS, a further polishing upflow reactor using elemental sulfur and oyster shell mixture was used to facilitate autotrophic denitrification prior to discharge to a disposal area. In the present study only the first reactor area was tested and contained an 18-inch layer of sawdust-sand mixture underlying an 18-inch layer of loamy sand. Dispersal to the top of this reactor bed was accomplished by a low-pressure distribution system using GeoMat™ (figure 3). A final disposal area was not included in the present study, however data from the discharge will be used to determine the requirements for final disposal. The decision to use loamy sand (a commercial blend of sand and soil used in golf courses) was based on previous work at MASSTC that had shown that loamy sand preserved the alkalinity of the percolating wastewater (necessary for ammonia oxidation or nitrification) and buffered changes in pH. This was thought necessary for facilitating complete nitrification (a necessary precursor for denitrification) and maintaining a near-neutral pH (also thought necessary for complete nitrification). The assumptions that adequate alkalinity and pH neutrality were required conditions is based on generally-accepted stoichiometry. These assumptions are challenged by work presented below, but are presented here to explain the initial attempts to meet them.

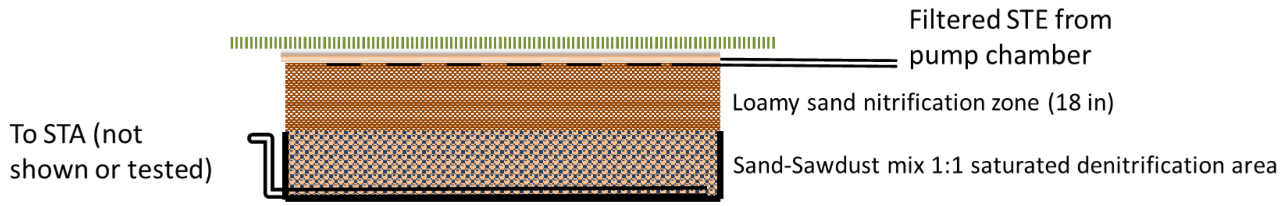


Figure 3. Saturated denitrification system design using a containment liner. Note the nitrifying layer is a loamy sand (60-440 Sand/soil, New England Specialty Soils, 435R Lancaster St Leominster, MA 01453). STA = Soil Treatment Area or leaching facility, STE = Septic tank effluent. DESIGN 1

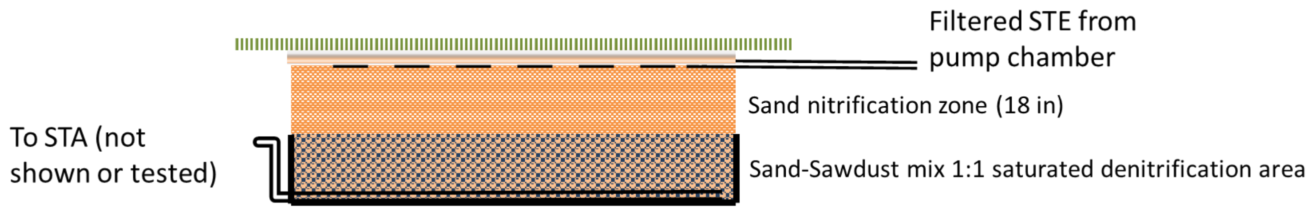


Figure 4. Saturated denitrification system design using containment liner. Note that nitrifying layer uses ASTM C-33 Sand (design 2) or sand provided by Stony Brook University and originating from Long Island, New York. STA = Soil Treatment Area or leaching facility, STE = Septic tank effluent. DESIGN 2 and DESIGN 3

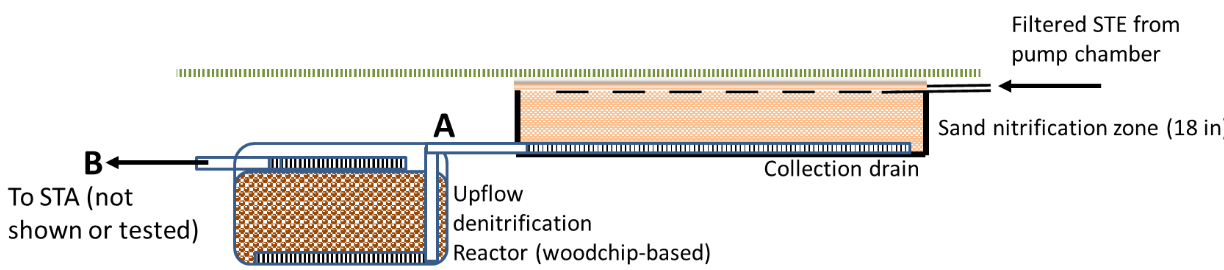


Figure 5. Denitrifying configuration with nitrifying STA percolate diverted through a container of lignocellulose. STA = Soil Treatment Area or leaching facility, STE = Septic tank effluent. A and B denote sampling locations. DESIGN 4

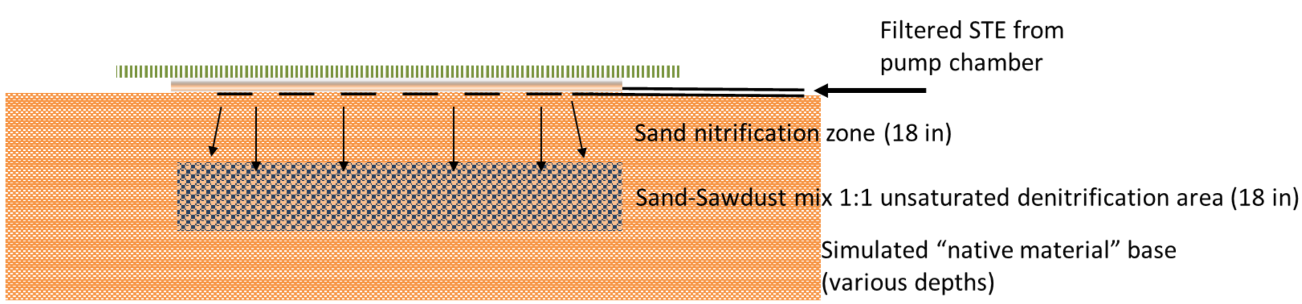


Figure 6. Unsaturated system design constructed in sand provided by Stony Brook University and originating from Long Island, New York. STE = Septic tank effluent. DESIGN 5

For over nine months following startup of the system, the Total Nitrogen (TN) levels in the final effluent of this system generally remained below 5 mg/L. Following this period, the nitrate in the percolate from the nitrifying layer of loamy sand began to decrease concurrent with an increase in ammonia (figure 7). Since the major processes in denitrification prerequire the oxidation of ammonia to nitrate, the major increases in TN were due to the ammonia passing through the denitrification layer unchanged (figure 8).

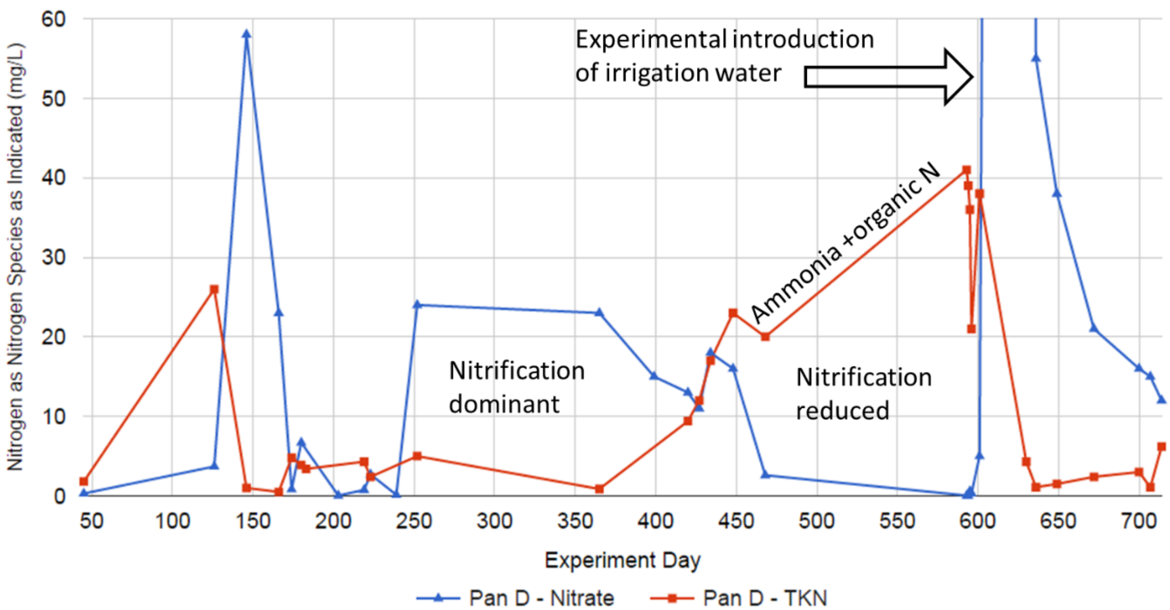


Figure 7. Nitrate and Total Kjeldahl Nitrogen (TKN) collected at the bottom of the nitrifying layer in the saturated denitrification system design using a containment liner (see figure 3). Note extremely high (>300 mg/L) nitrate following a rapid introduction of irrigation water.

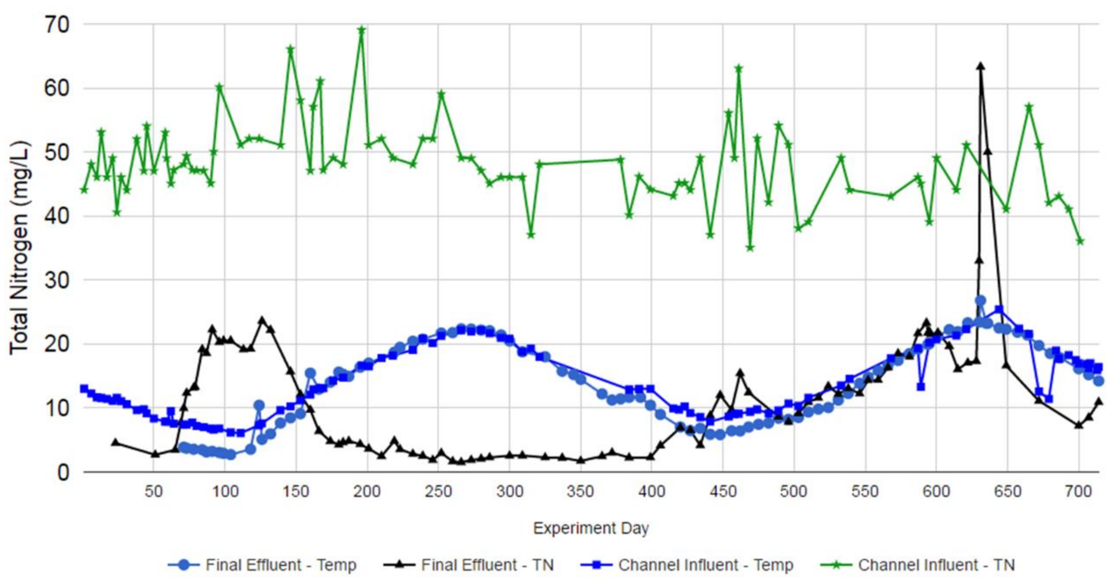


Figure 8. Total nitrogen concentrations with temperature in the saturated denitrification system design using a containment liner (see figure 3).

Because all other functioning systems exhibited decreasing nitrogen with increasing air and influent temperature, it was decided to interrupt the flow to the system and excavate selected areas for inspection. In addition, it appeared that some of the areas were not freely draining and some areas of wastewater surfacing were observed. On July 27, 2016, approximately 600 days following startup, inspection revealed that the soil column under the distribution system was not freely draining and the soil remained wet between dosing cycles. It was thought that this likely was the cause for decreased nitrification. On August 3, 2016 following a two-week period of no influent supply we conducted an experiment which involved the watering of the top of the system with approximately 300 gallons (nominally one gallon per square foot of area) of tap water within 30 minutes. The results were sudden and striking with nitrate levels elevating to 300 mg/L in the pan lysimeter located at the interface of the nitrification and denitrification interface (figure 9). The data suggest a rapid response by nitrifying bacteria to mobilized ammonia released from the wastewater soil interface as a result of the irrigation flooding with tap water.

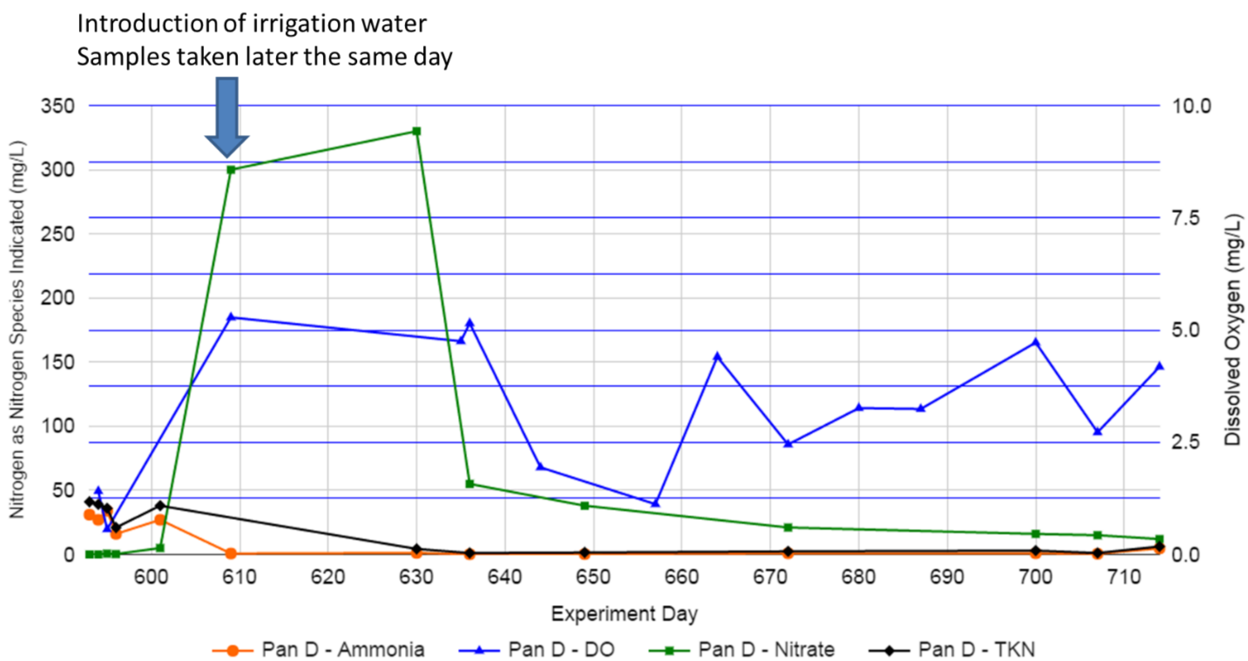


Figure 9. The response of the unsaturated layer of the saturated system to an intense irrigation event on August 3, 2016.

The response to the pulse of nitrate passing through the system was observed at the final discharge point approximately three weeks following the irrigation event (figure 10). Even challenged with > 300 mg/L nitrate-nitrogen, the denitrification layer reduced the nitrate by at least 80%.

The system was subsequently run under normal influent flow until November 15, 2016 when flow was stopped due to an anticipated forensic excavation with Stony Brook University. It was decided that since the loamy sand showed signs of hydraulic stress in spring 2016, the nitrification layer would be replaced with ASTM C33 sand to closely approximate an installation of a saturated system for Stony Brook University which would use sand from Long Island that met the ASTM C33 specifications.

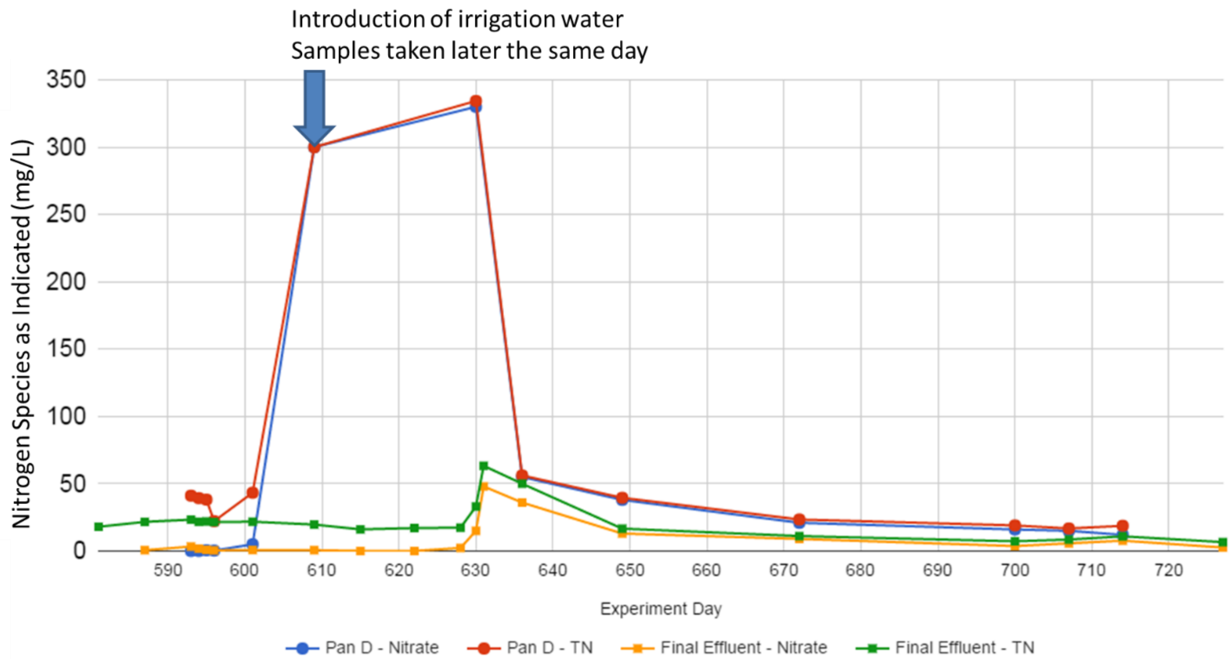


Figure 10. Comparison of nitrogen species between the nitrification layer (as represented by the pan lysimeter (Pan D) at the nitrification-layer denitrification layer boundary) and the final discharge from the denitrification layer during a selected period of operation.

CONCLUSION – DESIGN 1

The cause of the hydraulic stress and diminished nitrification during the spring of 2016 is undetermined. The hydraulic loading rate of 0.5 gal./sq. ft./day was initially within the loading rates specified in the soil type by the Massachusetts Code (Title 5 – 310 CMR 15.242). During the excavation, split-ring permeameter test run at the wastewater/soil interface indicated an acceptance rate of 10 – 15 min/inch. This rate compared favorably with the assumed rate of 10 min/inch at installation, again supporting the appropriateness of the loading rate by the prior-cited requirement. There were minor construction faults observed (a few low areas where wastewater collection was observed), however these areas could not account completely for the observations of reduced nitrification. At the time of excavation, researchers from Stony Brook University took many core and bacteria samples which will be examined in the coming months.

The decision of Stony Brook to install a system with similar design but using materials from Long Island, and to use sand in the nitrification layer (as opposed to the loamy sand used above), compelled this project to modify the design in November 2016. Leaving the denitrification layer in place, we removed the nitrification layer and replaced the loamy sand with locally-sourced "Title 5 sand" that met the specifications of ASTM C33. The results of this modification are presented below.

DESIGN 2 - Operation of the above following replacement of the loamy sand with ASTM C33 Sand.

In November-December 2016, the cover, distribution system and nitrification layer of the above system (DESIGN 1) was removed and numerous soil core samples were taken and are being analyzed for bacteria species by Stony Brook University. The Loamy sand was replaced with standard “Title 5” sand fill meeting the same specifications as ASTM C-33. The hydraulic loading was resumed at approximately 0.5 gal/sq. ft./day based on the areal coverage of the bed (areal area ≈450 sq. ft., daily load ≈220 gallons). The reduction in total nitrogen of this rebuilt system followed a similar pattern as the original installation (figure 11).

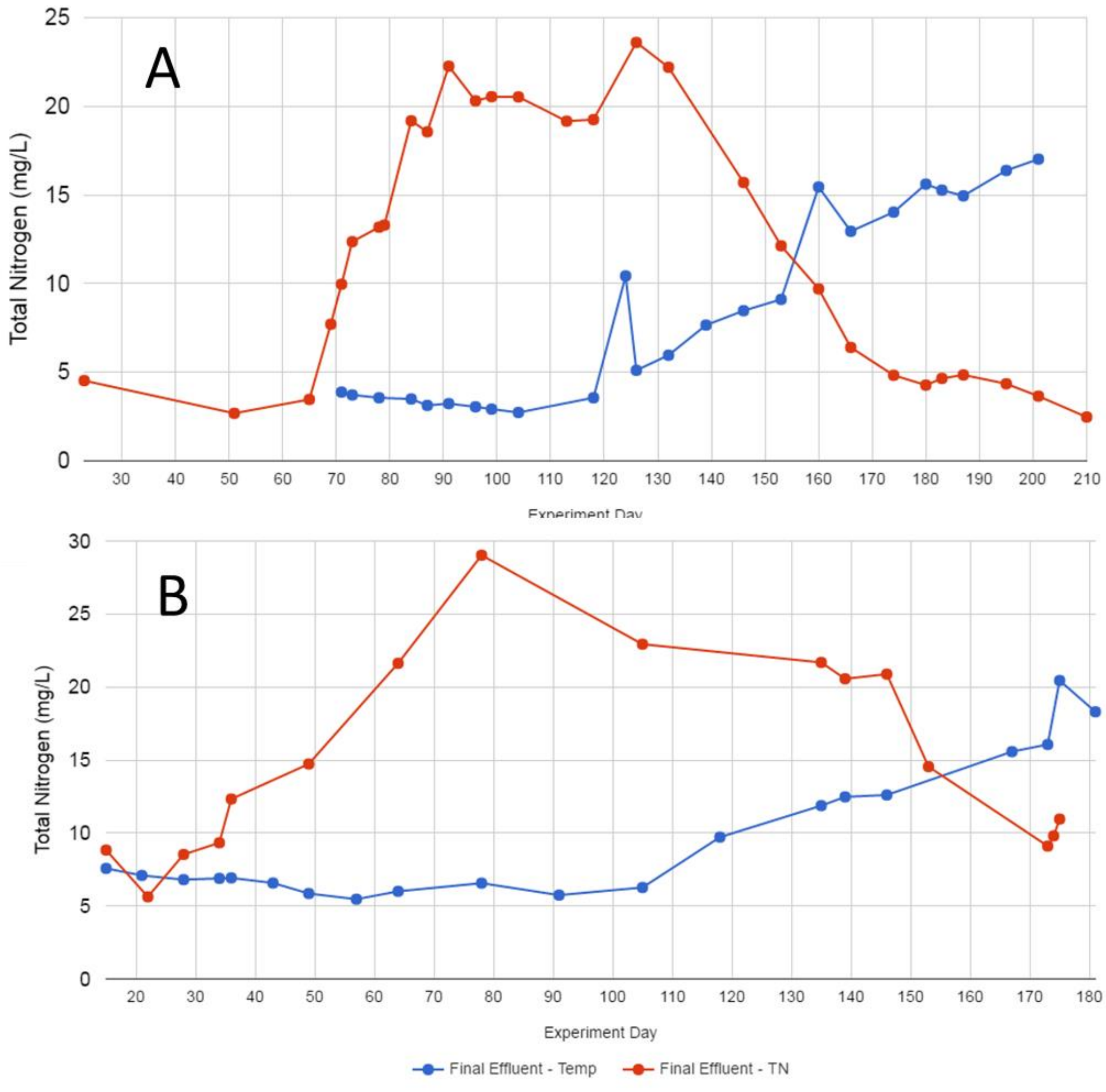


Figure 11. Comparison of the “start-up” nitrogen removal between DESIGN 1 (A – Operated December 2014 – November 2016 containing loamy sand as nitrifying layer) and DESIGN 2 (B – Operated since December 2016 containing ASTM C-33 sand as the nitrifying layer). Note similar time periods for removal of TN to levels below 10 mg/L.

Since both systems were started at the same time of year (going into winter), their start up performance can be compared. The data suggest that the loamy sand and the sand perform similarly, showing a level of 10 mg/L TN is achieved within 160-170 days of startup.

A closer inspection of the data shows that the first two months of operation, there is an approximate 50% reduction in TN which is likely due to the uptake of bacteria during the growth phase and its retention in the organisms themselves.

This system will remain in operation and will be monitored for at least the next two years.

CONCLUSION - DESIGN 2

As previously discussed, the reasons for the hydraulic stress in DESIGN 1 were not determined, but we posit that the blended soil (loamy sand) changed drainage characteristics over time due to unknown factors involving both the physical (migration of fine materials and subsequent reduction in hydraulic capacity) or the biology (growth of clogging organisms at a rate exceeding their senescence and decline). DESIGN 2 was an attempt to standardize the nitrification layer with a known and accepted media that is required in Massachusetts Regulations (310 CMR 15.000 – Title 5). In addition, this modification will allow a direct comparison with DESIGN 3 which is the same design using materials sourced from Long Island.

DESIGNS 3 – 5 Origins

This and previous Project 14-01 319 generated significant interest by Stony Brook University (SBU), Center for Clean Water Technology who was tasked with investigating non-proprietary means for nitrogen removal in Suffolk County (Long Island), New York. Following a design charrette with consultants Hazen-Sawyer (who was instrumental in completing the FOSNRS), University of Rhode Island personnel (George Loomis - University of Rhode Island, Research and Extension Soil Scientist and the Director of the New England Onsite Wastewater Training Center and José A. Amador – Professor Laboratory of Soil Ecology and Microbiology University of Rhode Island), researchers from Stony Brook University, regulators from Suffolk County and others, it was decided that this Design 2 should be duplicated using Long Island-sourced material. With support from SBU, the following three systems were installed at MASSTC in late-July and August 2016. In addition, the unsaturated design like those reported on previously (Project 14-01/319) was also duplicated using Long Island sourced materials. Finally, a design in which a shallow drainfield percolate is diverted in an upflow fashion through a container of woodchips was also installed and tested. Most of the monitoring for these systems was supported under this project and we advance this as a key achievement in leveraging this project funding with the construction and limited sampling support from SBU.

DESIGN 3 - A saturated system similar to DESIGN 2

This design substitutes “Long Island Sand” for the sand in both layers and “Long Island mulch” in place of the sawdust. It was installed with support from Stony Brook University. This system was installed in July 2016 and began operation in August.

Similar to DESIGN 1 and DESIGN 2, we observed a negative correlation between temperature and overall nitrogen removal in this saturated system (figure 12).

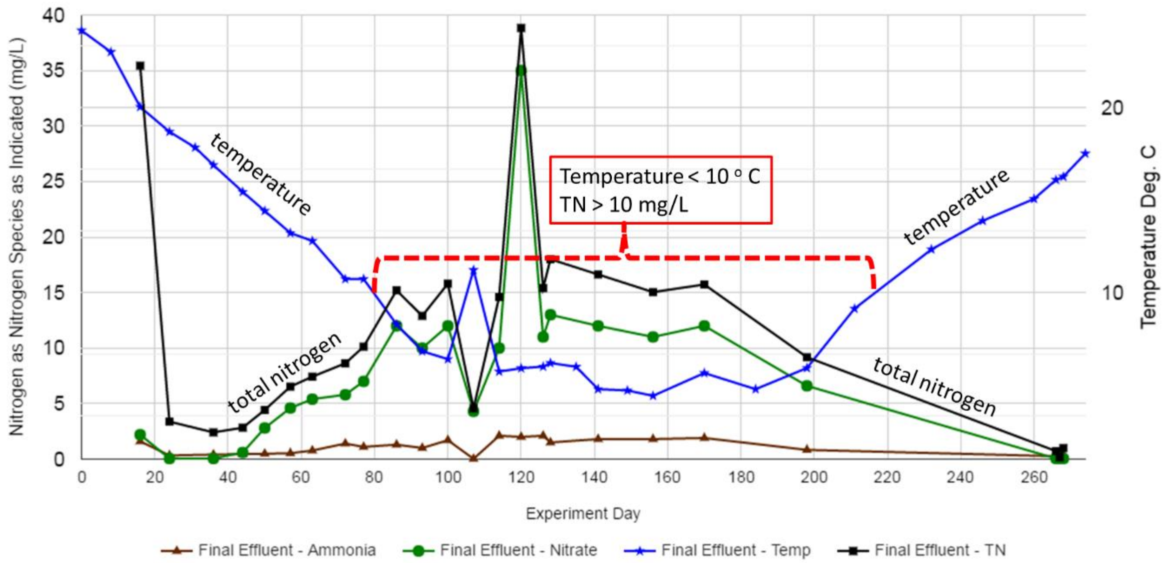
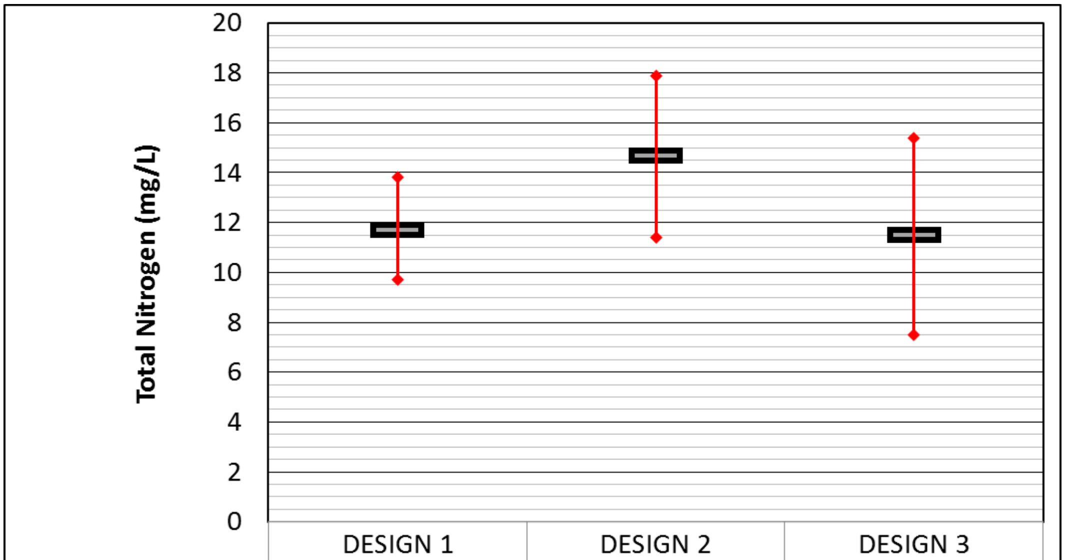


Figure 12. Concentration of selected nitrogen species with temperature at the discharge of the saturated system installed with support from Stony Brook University at MASSTC in July 2016. Shaded area denotes TN < 10 mg/L.

The data suggest that discharge TN concentrations below 10 mg/L occurs when the temperature of the discharge exceeds 10°C. This relationship between temperature and TN concentration was like that observed in DESIGN 1 (figure 11 a). The data also indicate that the nitrification is not limiting during the colder months as over 75% (67 – 94%) of the TN in the discharge is made up of nitrate and only 10% (5 – 14%) was made up of ammonia. Thus, it appears that the condition limiting the denitrification in the colder months is the reduction of nitrate to nitrogen gas and not the prerequisite oxidation of the ammonia to nitrate. An examination of the dissolved oxygen levels in the discharge reveal that, excluding a single aberrant value, the average oxygen concentration in the effluent was 0.27 mg/L (0.18 – 0.36 mg/L, *p=.05*) which would appear to support the reduced conditions necessary to reduce the nitrate. We conclude that the denitrification step is more sensitive to temperature than the nitrification step in this design type.

CONCLUSION - DESIGN 3

This design, like DESIGN 1 and DESIGN 2, relies on a saturated zone of sand and sawdust for denitrification. All these designs exhibit a seasonal reduction in performance for nitrogen removal with DESIGN 2 (the most recently installed and started up during late autumn) having the most profound loss of performance in the first winter (figure 13). In saturated designs such as these, there is less question as to the longevity of the sawdust used, with most estimates exceeding 50 years.



	DESIGN 1	DESIGN 2	DESIGN 3
Upper CI (p=.05)	13.8	17.9	15.4
Lower CI (p =.05)	9.7	11.4	7.5
Mean	11.7	14.7	11.5

Figure 13. Comparison of Total Nitrogen at discharge points for DESIGNS 1, 2 and 3 (mean TN and 95% Confidence Limits). CI = Confidence Interval.

Although the saturated design system is minimally complex to construct and has a more-proven denitrification media longevity, the system as described in the three designs above requires an area for final effluent/percolate disposal. Potential designs for this final disposal area vary and may be an area that surrounds or is adjacent to the containment area and variously sized. In the Florida locations, a complete second STA was constructed. Since the wastewater exiting the containment area after denitrification following a start-up period is generally < 20 mg/L $BOD_{5\text{-day}}$, the final disposal soil-contact area can be greatly reduced (hydraulic loading rate can be increased). The exception to this was DESIGN 1 in which there was a four-month period where the average $BOD_{5\text{-day}}$was 144 mg/L (< 10 mg/l at all other times). In Long Island, New York, officials are considering the use of existing cesspools as a final disposition for the discharge of this design, thus maximizing the use of existing infrastructure and minimizing the cost to the homeowner.

DESIGN 4 - A nitrification layer underdrained and diverted to a box of woodchips.

This design offers the opportunity to closely inspect each of the nitrification and denitrification processes, since each process occurs in a separate container in the system and there is a discrete sampling point between the two processes. The nitrification area is basically a full-sized underdrained soil absorption system that can be considered a slow-rate sand filter. That bed contains 18 inches of sand sourced from Long Island and that meets the specifications of ASTM C-33 and is hydraulically loaded at 1.2 gal/sq.ft./day[a]. A bottom drain in this area diverts the percolate to the bottom of a 1500-gallon tank filled with oak woodchips. Samples were taken following the nitrification bed prior to the

[a] This loading rate is calculated on the actual contact area of the wastewater dispersal device (GeoMat™) and the soil and not the areal area of the system.

diversion to the wood chip container (figure 5 sampling location "A"). Samples taken at this location indicate that despite low temperatures during late autumn and winter, nearly complete nitrification continued with most of the TN observed as nitrate and minimal ammonia present in percolate (figure 14).

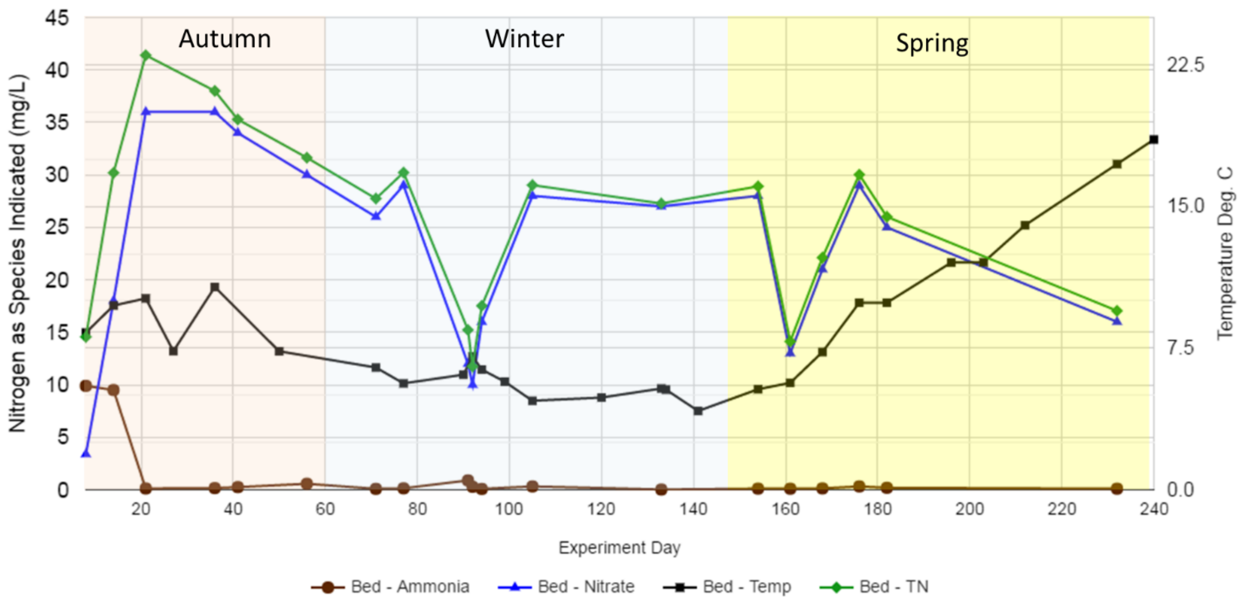


Figure 14. Nitrogen species in percolate beneath nitrification bed in DESIGN 4. Samples taken prior to discharge to the denitrification container (figure 5 location "A").

The two periods of depressed TN occurred shortly after rainfall events of at least two inches. These data suggest that in soils-based denitrification systems, nitrification is not the limiting condition even during colder months of the year. Nitrogen concentrations in the discharge of the *denitrification portion* (location B – figure 5) of the system averaged 3.6 mg/L (2.3 – 4.8 mg/L, $p= .05$). The remaining TN in the discharge was primarily comprized of Total Kjeldahl Nitrogen (TKN), about 5 – 20% of which is ammonia. There are three notable exception to this trend (figure 15). In each of these instances, nitrate is the main constituent of the TN. These events were related to precipitation events prior to or during the sampling. We posit that the precipitation results in increased flow rates through the denitrification chamber and hence decreased residence time during which denitrification could occur. Despite this apparent vulnerability of the technology to upset, >90% of the observed values were < 10 mg/L TN and >70% of the TN values were < 5 mg/L TN.

CONCLUSION DESIGN 4

This design exhibited the most stable denitrification among the designs tested. Despite influent temperatures (percolate from the nitrification bed) below 5°C, denitrification continued. The decreases in performance related to precipitation events apppeared shortlived. As with the other designs, this design would require a structure for final disposition of effluent,

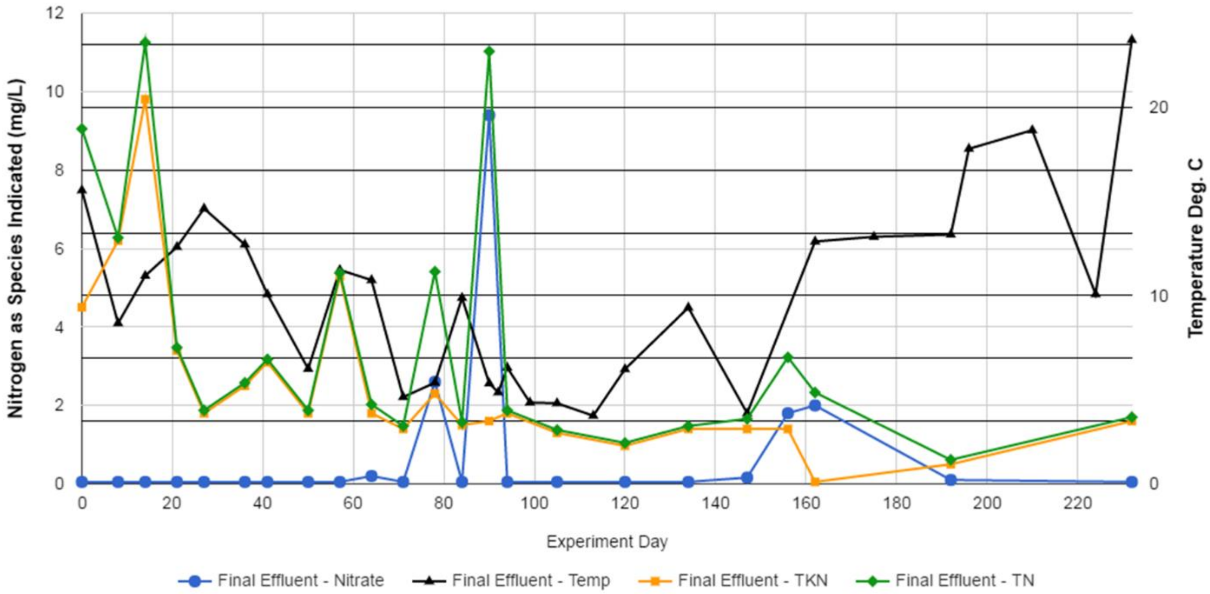


Figure 15. Nitrogen levels in discharge from denitrification area of DESIGN 5.

A major advantage to this design is the accessibility of the denitrification media for inspection and replacement. A disadvantage of the system as tested is the need for a final disposal area. In Long Island, the sponsors of the installation at Stony Brook University are considering the possibility of using existing cesspools on a property as a final disposition for the system discharge. To examine this potential, we examined the Biochemical Oxygen Demand ($BOD_{5\text{-day}}$) of the effluent since we posit that the wood-based carbon source may add significantly to the BOD of the final effluent. During the first four months of operation, the average of five BOD measurements was 440 mg/L. Thirteen subsequent measurements taken from November 2016 to June 2017 show and average of 36 mg/L. We conclude that more research should be performed regarding the sustainability of smaller final soil absorption systems for this technology, however data would suggest at least a 50% reduction in final STA could be sustained with this quality of effluent.

DESIGN 5 - Unsaturated system similar in dimensions to the silty-sand-sawdust system reported in Project 14-01 319 but substituting sand and sawdust from Long Island, New York sources.

The final design examined under this project was installed with support from Stony Brook University and closely followed the silty-sand-sawdust system reported previously under Project 14-01 319. The major difference between the two designs is the substitution of standard sand fill for the silty sand and the percentage of sand:sawdust (figure 16). DESIGN 5 contained a 1:1 mix sand:sawdust in the denitrification layer, while the system reported on in Project 14-01 319 used a 1:5 sawdust:sand-silt media mix. Design 5, along with sampling locations is illustrated in figures 16 and 17. Paired lysimeters were installed on each side of the system to enable some controlled experiments involving precipitation to be conducted in the summer of 2017. This design is the simplest design to install in the field since it does not involve the use of containment liners and is simply a modification of the fill material used beneath a low pressure dosed dispersal system.

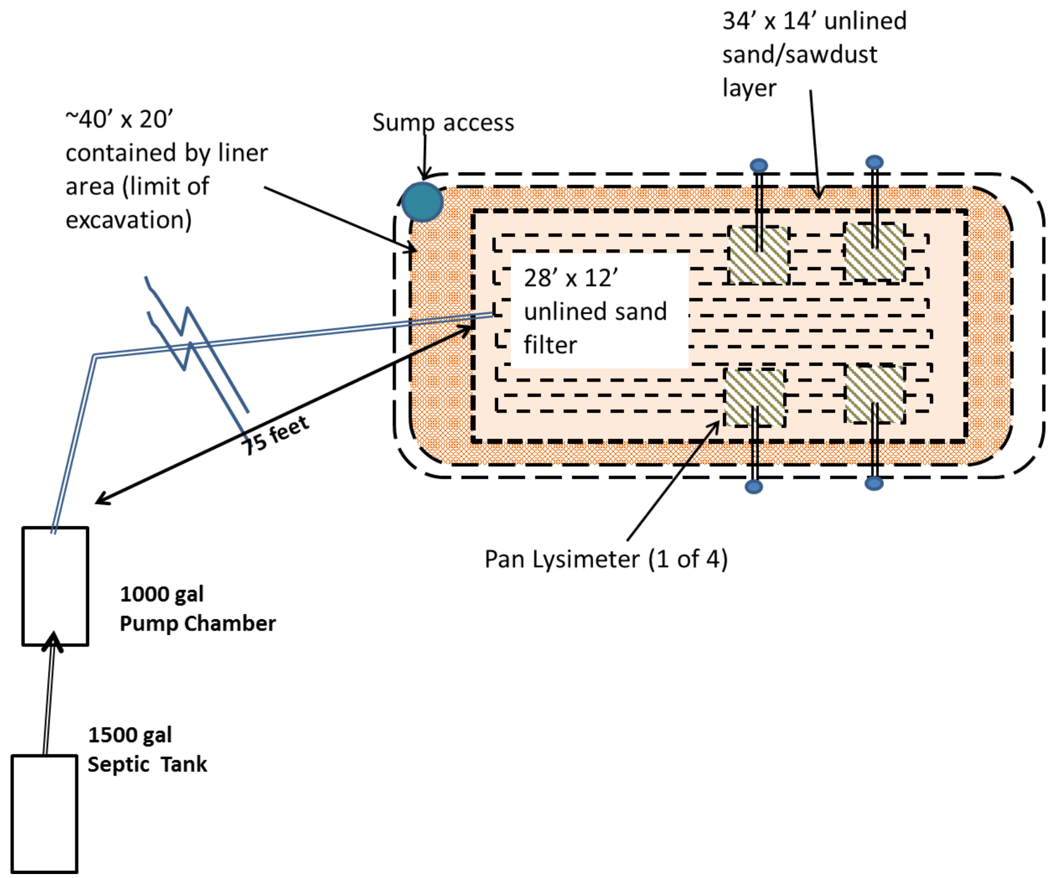


Figure 16 Illustration DESIGN 5 showing component and sampling locations.

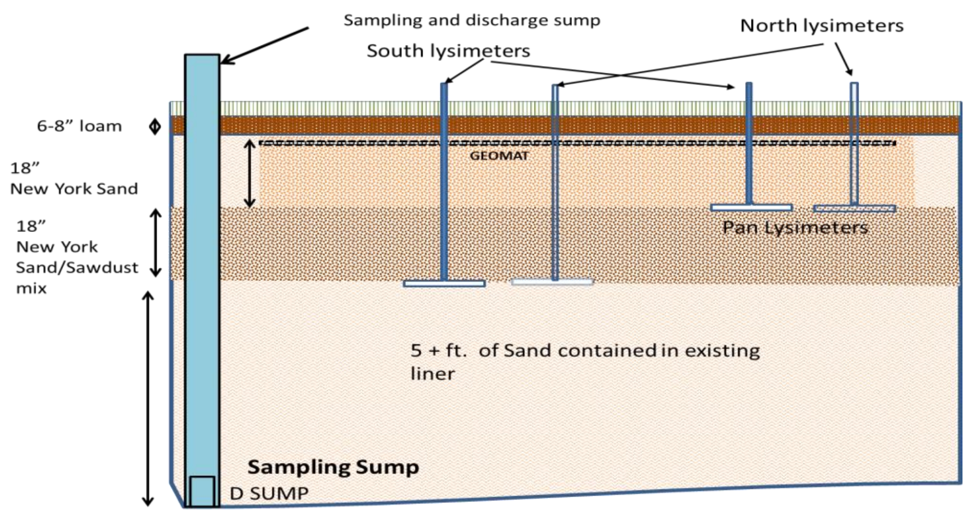


Figure 17 Profile illustration of DESIGN 5 - Unsaturated flow system.

Total nitrogen (TN) concentration for the first 250 days from samples collected in the sump under the entire system averaged 9.9 mg/L (8.5 – 11.3 mg/L, $p=.05$, n= 26)[b]. Although some seasonality is suggested (figure 18), this will be confirmed only after another year of operation. TN samples collected directly beneath the system in a pan lysimeter averaged 6.4 mg/L (4.7 – 8.2 mg/L, $p=.05$, n=21) are significantly different than the sump ($p=0.003$), indicating that the sump had higher concentrations of nitrogen than the lysimeter. While we would expect that there might be some differences due to the collection area of the sump (20' x 40') compared with the pan lysimeter (2' x 2') we have no explanation for why the sump would have higher TN levels unless some short-circuiting of percolate flow occurred around two 4-inch pipes that were left in the test cell from previous testing.

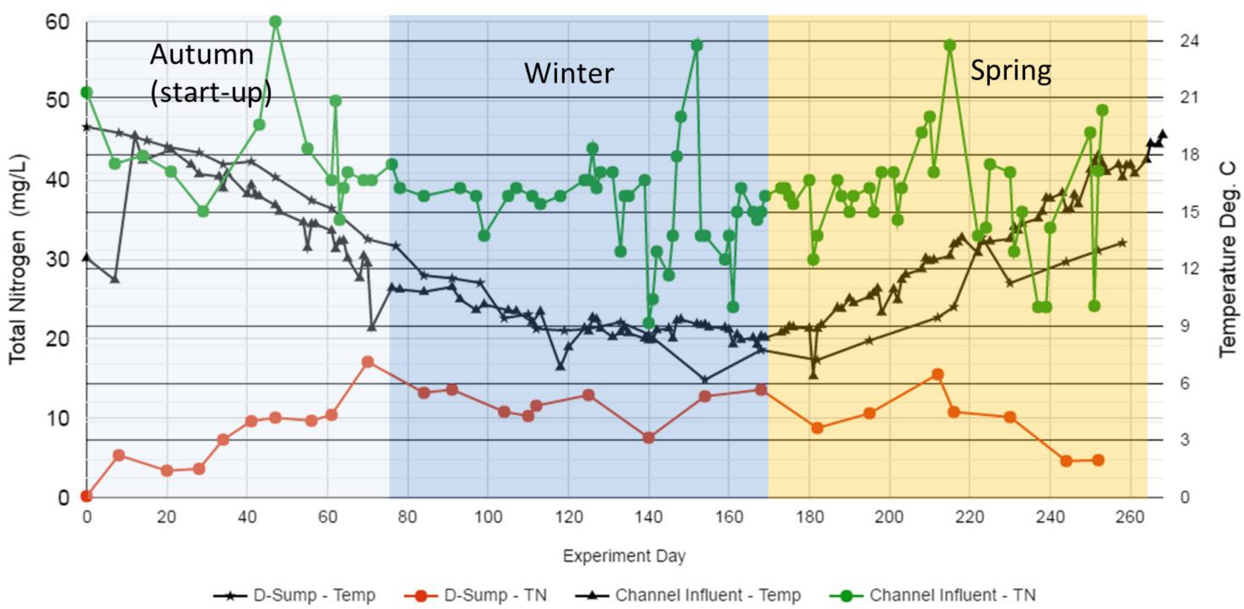


Figure 18. Total Nitrogen (TN) concentration in percolate beneath DESIGN 5, an unsaturated flow system installed at MASSTC. "D-Sump" = percolate beneath the system, "Channel Influent" == the raw wastewater supplied to the septic tank.

As with the other designs, it appears that nitrification is not limiting, even during the colder months. Sump samples beneath the system show that the TN present is predominantly in the form of nitrate with ammonia comprising <3% of the nitrogen on average (figure 19). The remaining organically bound nitrogen constitutes an average of 6% of the TN in the percolate.

CONCLUSION – DESIGN 5

In comparison with DESIGNS 1 – 4, DESIGN 5 is the simplest to construct in the field since no liners are required and basically an 18-inch layer of standard fill material is substituted with a mixture of fill material and sawdust. In addition, and in contrast to the other designs, this design does not require a separate facility for the final disposition of the treated effluent. Since this system has only been in operation since August 2016, we cannot yet determine the long-term performance. As opposed to the

[b] First value of 0.2 mg/L was not used in this calculation as it was considered luxury uptake by organisms.

saturated designs (DESIGN 1 – 4), the sawdust/cellulose in this design would appear to be more vulnerable to aerobic decomposition.

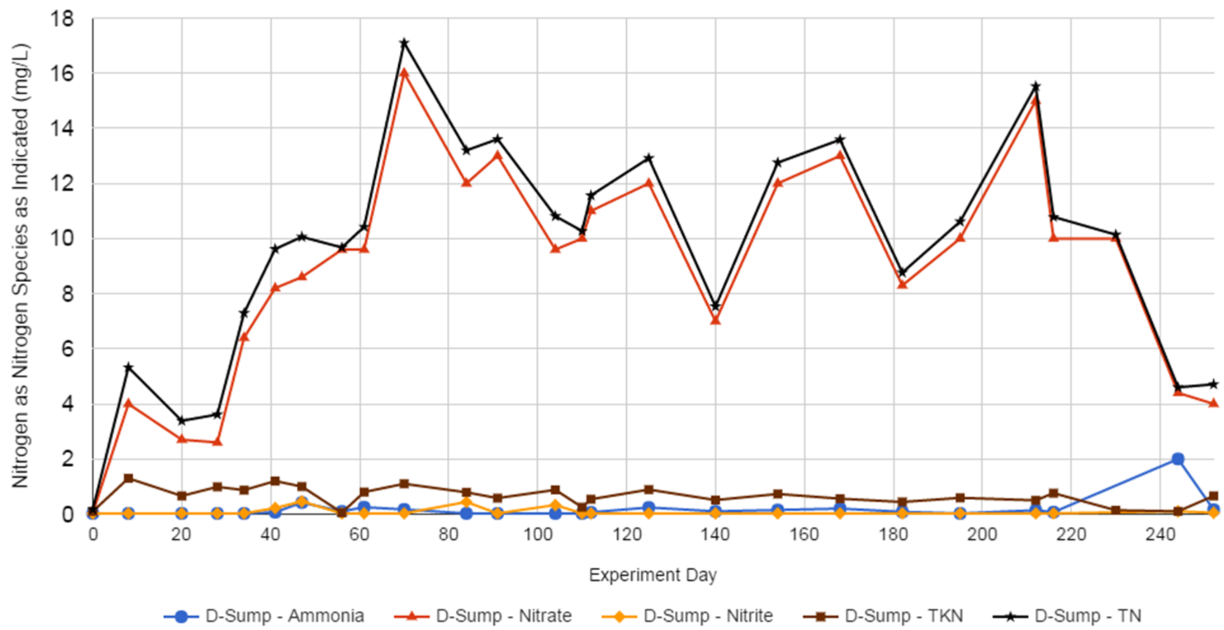


Figure 19. Nitrogen concentrations (mg/L) by species in effluent (percolate) of DESIGN 5.

The release of carbon dioxide in the aerobic process could reduce the long-term ability of the sawdust to provide carbon for the organisms responsible for denitrification. To address this possible shortcoming, collaborators on this project convened a design charrette on October 25, 2016 at the University of Rhode Island. Participants used a newly developed data display tool to review all data collected to that point by this project and Project 14-01 319. The group decided that the following design modifications would be introduced to field installations to enhance anoxia in the denitrification layer of the system.

- A layer of peastone gravel will be placed immediately below the denitrification layer. Since the sand :sawdust layer is finer textured than the gravel beneath it, there will be a restriction in the water flow and an area of saturation above the gravel layer[5]. This saturation will occlude oxygen and oxygen transfer and hopefully enhance the anoxia.
- An impervious vertical liner will be placed around the denitrification layer. This liner will further restrict the exchange of oxygen from the adjacent soil areas.

These modifications are not expected to introduce significant complexity to the design since the practice of layering peastone and installing impervious barriers are common practice in septic system installation. These changes were summarized in an informational flyer for designers and is included in Appendix 1.

STUDY CONCLUSIONS AND FURTHER STEPS

We conclude from the present project and Project 14-01/319 that there is potential for significant nitrogen removal from onsite septic systems by making simple modifications to the Soil Treatment Area -STA (aka drainfields) using various configurations of lignocellulose and sand media. Following a review of the extensive work done by the Florida Department of Health[1] and discussions with those researchers and others, this project endeavored to install and test the simplest, most cost-effective and sustainable means of achieving nitrogen removal from onsite septic systems. The understanding gained from the Florida Onsite Sewage Nitrogen Reduction Strategies (FOSNRS) Project and work by others[2,3,6], informed our decision to test the five systems reported on herein at the Massachusetts Alternative Septic System Test Center. These efforts are also in collaboration with Center for Clean Water Technology - Stony Brook University and the Suffolk County New York Health Department and offer an unprecedented opportunity to involve academic researchers and regulators in our efforts.

Each design was installed in full-scale, which we considered to be a minimum of 220 gallons per day. Beyond this flow, we consider the required sizing of the system to progress in linear fashion to all single-family home applications and possibly beyond. For example, a system design required for 440 gallons per day, which is equivalent to a four-bedroom house requirement under Massachusetts regulations, would be twice the areal area as the systems that we tested, which were sized equivalent to requirements for a two-bedroom system under Massachusetts regulations.

Among the most significant findings of this work is the documentation of the differences in results compared with the Florida studies, which are likely due climate differences. Since all the wastewater processes involving nitrogen transformations are controlled by temperature, we expected that the final extent of denitrification might be variable throughout the year at our latitude and show a diminishment of performance during the colder months. This was verified in each system to some extent with DESIGN 4 (nitrifying bed diverted to a container of saturated woodchips) exhibiting the least reduction in performance in the cold weather. Another significant finding was that in the colder weather the limiting step in the denitrification process was the reduction of nitrate to nitrogen gas. This is contrary to the common belief that nitrification or the oxidation of ammonium to nitrate is the limiting step in denitrification in cold climates. This common belief, likely deduced from larger wastewater treatment technologies, is apparently not true for soils-based denitrification processes. This knowledge will be used to consider design changes that might optimize the overall denitrification.

Four of the designs tested under this project require final disposition of effluent. Our studies indicate that DESIGN 2 and DESIGN 3 (both saturated systems with sand as the primary media), could be served by reduced-size final disposal areas since their final effluent $BOD_{5\text{-day}}$ (BOD) averaged < 15 mg/L, which would meet the criteria for many states' reduced sizing requirements. DESIGN 1 (a saturated system similar to DESIGN 2 and 3, but which used a loamy sand in the nitrification layer, exhibited a five-month period high BOD (40 – 240 mg/L) which will require consideration of a larger final disposal area, as did DESIGN 4. Since these designs require a final area for disposal, future efforts will involve a determination of the configuration for these final disposal areas, focusing on optimizing total system size and reducing costs.

DESIGN 5 was the simplest design and holds the promise of being the most economical system investigated. Although early in its testing (9 months), this design indicates that the TN can be reduced by ≈75%. Longer-term testing will be needed to evaluate project this system's performance. Data suggest however that this system will perform comparable to the silt-sand-sawdust system reported on in Project 14-01 319. These findings are the basis of a grant request under the EPA SNEP Coastal Watershed Restoration which will be installing 12 systems in the next two years for the evaluation of this technology. The questions regarding the longevity of the media remain to be addressed, however some researchers indicate that carbon depletion will occur over decades[6].

Continued Operation of the Massachusetts Alternative Septic System Test Center (MASSTC)

During the two projects referenced, MASSTC continued to sponsor both standardized testing for the onsite wastewater industry and research and development efforts sponsored by private parties. New technologies are now in development that have been encouraged by our efforts to develop non-proprietary ones supported under Projects 14-03/319 and 15-07/319 . Some of these technologies are using cellulose-based denitrification in part in response to efforts supported under these grants. MASSTC is presently also involved in two "spinoff" grants from the Massachusetts Clean Energy Center (CEC) that encourages businesses involved in wastewater products that relieve large infrastructure of some of the wastewater loads. These are grants given to the companies involved and MASSTC participation involves providing consultation and test-bed facilities. CEC is also engaged in determining the viability of MASSTC and other potential test-bed sites for their ability to encourage innovation and economic development. It appears from the investment from the private industry and research being conducted, such as was supported by the two grants, that MASSTC is a beneficial public-private partnership which allows the Commonwealth the advantage of having a facility to answer some research questions regarding their regulations pertaining to onsite wastewater and watershed management for contaminants, while concurrently serving as a facility at which private industry can research, develop and test products to address those same needs.

Literature Cited

1. State of Florida, *Florida Onsite Sewage Nitrogen Reduction Strategies Study Final Report*. 252 (2015).

2. Robertson, W., Blowes, D., Ptacek, C. & Cherry, J. Long-term performance of in situ reactive barriers for nitrate remediation. *Ground Water* **38,** 689–695 (2000).

3. Robertson, W. & Cherry, J. In situ denitrification of septic-system nitrate using reactive porous media barriers: Field trials. *Ground water* **33,** 99–111 (1995).

4. Robertson, W., Vogan, J. & Lombardo, P. Nitrate Removal Rates in a 15-Year-Old Permeable Reactive Barrier Treating Septic System Nitrate. *Groundwater Monitoring \& Remediation* **28,** 65–72 (2008).

5. Khire, M. V., Benson, C. H. & Bosscher, P. J. Capillary barriers: Design variables and water balance. *Journal of Geotechnical and Geoenvironmental Engineering* **126,** 695–708 (2000).

6. Robertson, W. Nitrate removal rates in woodchip media of varying age. *Ecological Engineering* **36,** 1581–1587 (2010).

Appendix 1

Construction Summary for Layered Soil Treatment Area (LSTA) to be installed under the Demonstration Project

A primer for board of health members, septic system designers and installers

Massachusetts Alternative Septic System Test Center

Construction Summary for Layered Soil Treatment Area (LSTA) to be installed under the Demonstration Project

A primer for board of health members, septic system designers and installers

Note: *The following describes a demonstration project by which Barnstable County Department of Health and Environment (BCDHE) in collaboration with others, intends to install modified Soil Treatment Areas (STA) alternately known as leachfields at various residential pilot locations to test their effectiveness. The following describes various aspects of the project and is meant for health agents, system designers and system installers.*

What is a Layered Soil Treatment Area (LSTA)?

A LSTA is basically a leachfield that is placed in layers, using materials that allow for the successive nitrification and denitrification of septic tank effluent as it percolates through the layers.

The Barnstable County Department of Health and Environment in collaboration with others and with information gleaned from many sources, has been experimenting with various configurations of LSTA at the Massachusetts Alternative Septic System Test Center over the past few years. We have received funding from various sources to place Pilot Systems at residences. To minimize the risk of failure at the pilot locations, certain design features have been incorporated in these pilot project sites and are described below.

Ideal sites for consideration of the layered system.

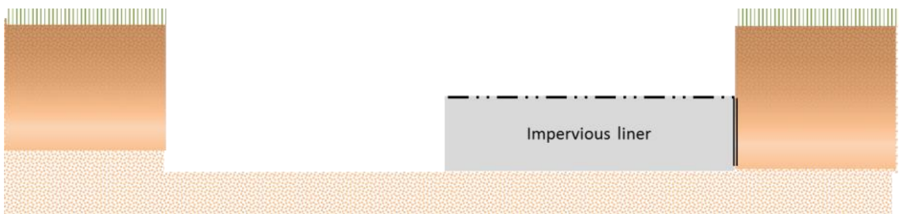
The ideal site for a pilot LSTA installation is one that enables a strip-out to an elevation of four feet below existing grade. In this excavation 18 inches of a sand-sawdust mix is first placed over a two-inch layer of washed pea stone followed by 18 inches of "Title 5" sand. Atop the sand layer, the distribution system will be placed (shallow pressurized drainfield product, drip dispersal). The placement of a liner/barrier around the lower sand/sawdust layer is also required. The sequence would be as follows:

STEP 1

Excavate areal area required to a depth of at least four feet.

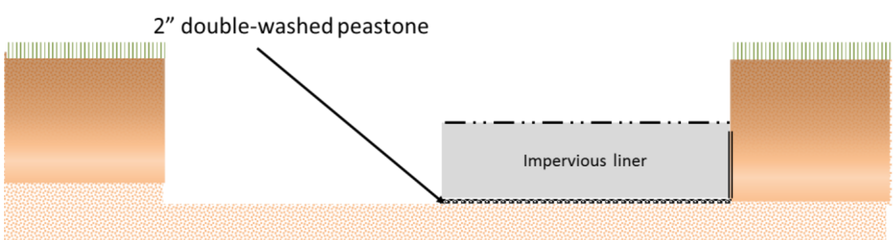
STEP 2

Place 20 mil impervious liner around perimeter of excavation ONLY ON THAT PORTION OF THE SYSTEM DESIGNATED TO RECEIVE THE PEA STONE AND THE SAND/SAWDUST MIXTURE. Hold in place with geotextile staples or other suitable method.



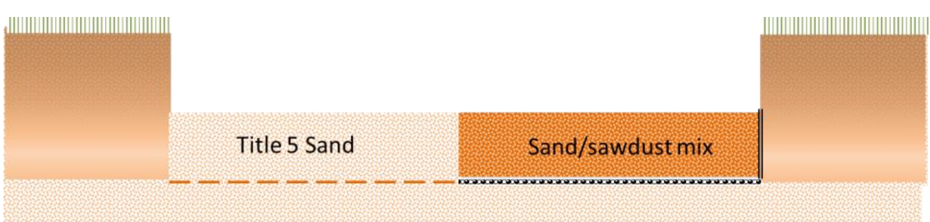
STEP 3

Place 2 inches of double-washed pea stone under portion of system that will receive the sand/sawdust.



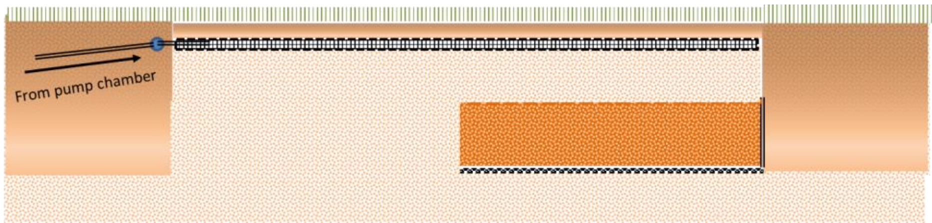
STEP 4

Place 18 inches of sand/sawdust mix in excavation (use light plate compactor after 12 inches and again at final grade to obtain 18 inches ONLY IN AREA DESIGNATED FOR TREATMENT. Fill the adjacent area with Title 5 sand.



Step 5

Place Title 5 sand to an elevation appropriate to the distribution method (drip, shallow pressurized drainfield, GeoMat™) 18 inches in depth above the sand/sawdust layer and install distribution system and cover.



Why is the sawdust in only half of the STA?

You will read above that certain measures are being taken to minimize the risk of placing this pilot system at their residence. The design team decided that splitting the system into halves has two advantages. Foremost, in the unlikely event that the sawdust mixture causes a hydraulic failure, the homeowner will still have the remaining Title 5 system to disperse wastewater. Secondly, the halving of the system will allow a comparison between the amended STA with a standard Title 5 system.

Is there another way to minimize the risk to the homeowner?

Yes. There are two configurations possible in the pilot. The ideal situation is where an installation of a complete Title 5 system and an additional half sized system with an amended STA. The two possibilities are sketched below.

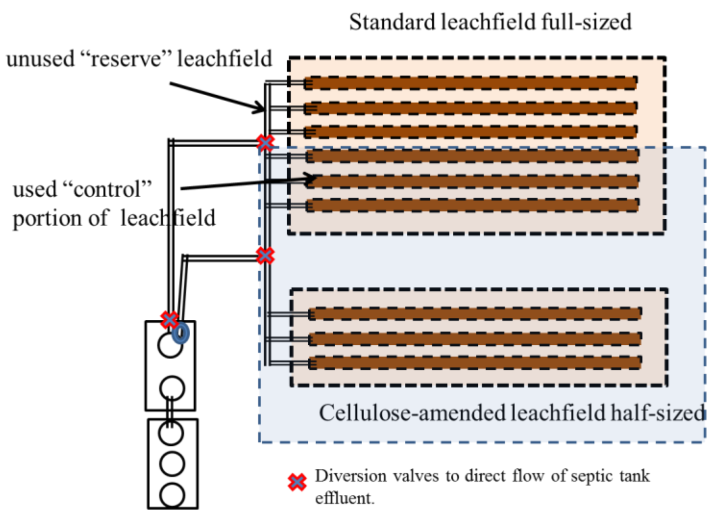


Figure A

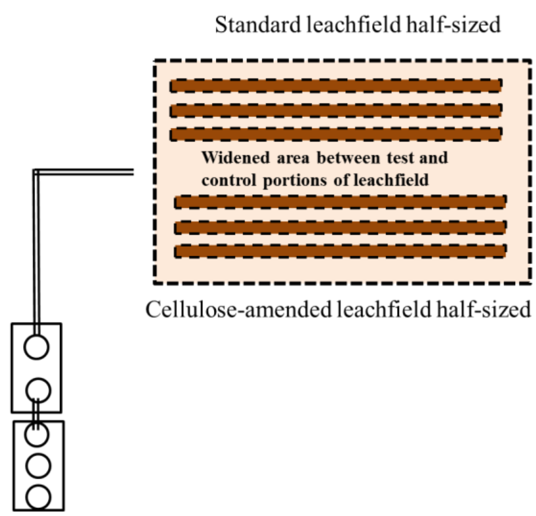


Figure B

Figure A above shows the situation where one-half of the Title 5 system is used in conjunction with a layered STA (LSTA). In the event of a failure of the LSTA portion, a few "diversion" valves as shown above are turned and the homeowner is left with a full-sized Title 5 system. In the event of a failure in the situation shown in Figure B above, the homeowner would have a half-capacity system.

Homeowners that choose to have a configuration like Figure B above will be asked to sign a waiver that releases the County, designer and the contractor from all liability in the event of a failure in the amended section of the STA. This is because if the amended portion of the STA fails hydraulically, the responsibility to replace the section of the STA would be the homeowner's. This legal paperwork is presently being drafted.

What about sampling of the system?

Under the grant, samples will be taken monthly for two years. Samples will be taken from the pump chamber as well as from a series of pan lysimeters under the system. In addition, water use and pump-run counters will be checked during each sampling event. Following the period of the grant, the homeowner will be responsible for causing an annual inspection of the system and any monitoring required by the Commonwealth's DEP. We anticipate that annual monitoring will be required and annual inspection and adjustment of the low-pressure distribution system will be needed. A checklist for this requirement is being prepared.

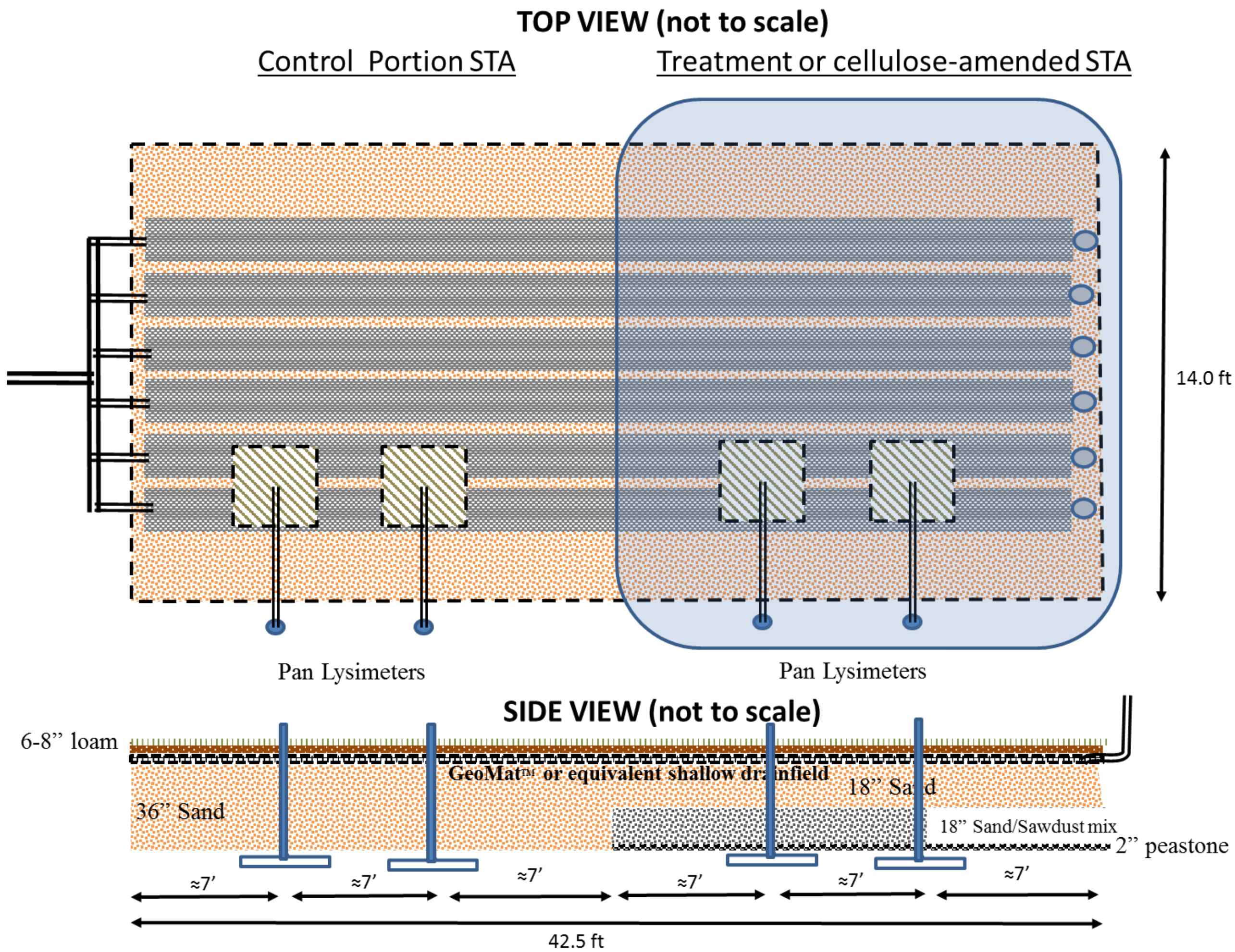
During each installation, pan lysimeters will be placed at four places (two under each of the STA and LSTA). Pan lysimeters are essentially "pans" that collect percolating water and convey it to a collection point. The placement of pan lysimeters is illustrated in a typical system below.

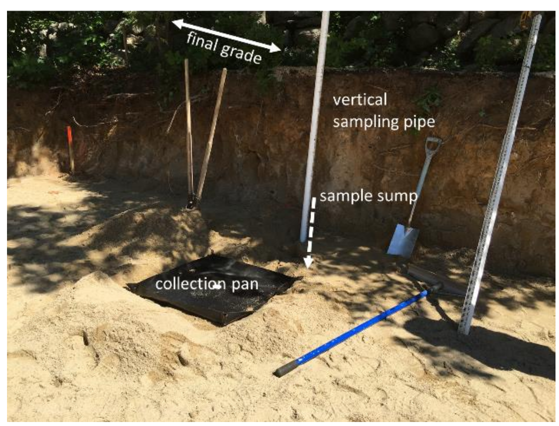
Will there be some assistance with permitting?

As part of the SNEP Grant, our partners at the Buzzards Bay Coalition have been helping with permitting. Korrin Petersen will attend the meeting of the board of health to answer questions, as may George Heufelder with Barnstable County Department of Health and Environment. We will also be providing assistance for system designers. In some cases, we will meet with the homeowners to make sure they understand the experimental nature of the project and their responsibilities for long-term operation and maintenance.

Long Term Maintenance?

As mentioned above and in accordance with Title 5, all pressure dosed systems must be maintained annually. The homeowners in this program will be informed and must agree to this and any other monitoring requirements. The systems will be registered with the Barnstable County Tracking Program and there will be online access to the information for your board of health.





Pan lysimeters will be fabricated and installed by staff of Barnstable County Department of Health and Environment. The vertical sampling port will be protected by a standard curb box. Other sampling ports may be required.

Other inspection ports and sampling devices may be installed. These installations may suspend fill operations for short periods of time and will be installed by personnel of the Barnstable County Department of Health and Environment.

Please remember

As we have said all along, the systems installed under this program are experimental. While we have taken design steps to minimize the risk of harm to the public health and environment, there is still some risk that the system may not perform to the expected standard. Some homeowners who allow a system sized at 1.5 x the design flow as described above will bear little risk of having to replace their system if there is some hydraulic failure (since we can merely turn a few valves and have a fully-complying leachfield. Others who install the system as in Figure B above will be signing a waiver noting that they will be responsible for any repairs necessary to the non-complying portion of the system should it fail by Title 5 criteria.

For designers, we will be available to consult on your design plans. In addition, any pressure dosed system designs that incorporate a Perc-Rite® Drip Dispersal System or a low pressure-dosed system using GeoMat® will have assistance from Oakson, Inc. or GeoMatrix LLC respectively. Other low-pressure dosed dispersal means over the nitrifying layer will be considered.

Barnstable County Department of Health and Environment will be holding some introductory sessions on the technology and the results in your area. If you are interested in attending one of these sessions, please send an email to George Heufelder at the email address below.

Project Partners

George Heufelder, Director – Massachusetts Alternative Septic System Test Center. Phone 508-375-6616 gheufelder@barnstablecounty.org
Brian Baumgaertel – Barnstable County Department of Health and Environment. Phone 508-375-6888 bbaumgaertel@barnstablecountyhealth.org
Korrin Petersen, Esq. – Senior Attorney - Buzzard Bay Coalition Phone: 508-999-6363 x 206 petersen@savethebay.org
George Loomis - University of Rhode Island, Research and Extension Soil Scientist and the Director of the New England Onsite Wastewater Training Center. Phone 401-874-4558 gloomis@uri.edu
José A. Amador – Professor Laboratory of Soil Ecology and Microbiology University of Rhode Island. Phone 401-874-2902 jamador@uri.edu
Damann Anderson and Josefin Hirst – Hazen and Sawyer, Tampa FL. Phone 813-549-2116 danderson@hazenandsawyer.com jhirst@hazenandsawyer.com

Appendix 2 – 6
Raw Data

Key

DO = dissolved oxygen in mg/L

TKN = Total Kjeldahl Nitrogen in mg/L

Temp = Temperature in degrees Celsius

CBOD = 5-day Carbonaceous Biochemical Oxygen Demand

BOD = 5-day Biochemical Oxygen Demand

TSS = Total Suspended Solids (mg/L)

Confidence Interval = 95%

Upper CI = Mean or Average + Confidence Interval

Lower CI = Mean or Average - Confidence Interval

Count = Number of Observations

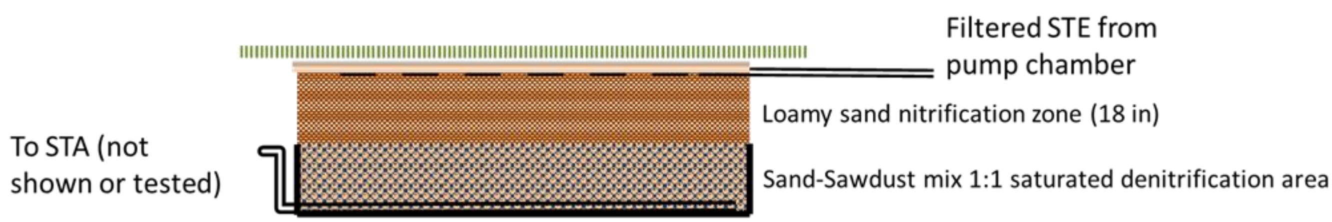
Ph – report in Ph Units

*** all nitrogen parameters reported in milligrams per liter (mg/L) - nitrogen

Appendix 2

Raw Data

DESIGN 1



DESIGN 1 - Raw Data

Saturated System Using Loamy Sand Nitrification Layer

Sample Date	Alkalinity	Ammonia	BOD5	DO	Nitrate	Nitrite	pH	Temp	TKN	TN
2014-12-02									4.3	
2014-12-12									2.9	
2014-12-25					2.30	0.025			2.2	4.5
2015-01-22					0.16	0.025			2.5	2.7
2015-02-05		2.30			0.06	0.005			3.4	3.5
2015-02-09	400	5.90			0.01	0.003			7.7	7.7
2015-02-11	410	8.30		0.11	0.03	0.240	6.40	3.9	9.7	10.0
2015-02-13	410	9.20		0.18	0.36	0.003	6.57	3.7	12.0	12.4
2015-02-18	430	12.00		0.21	0.16	0.022	6.39	3.6	13.0	13.2
2015-02-19	420	11.00			0.05	0.250			13.0	13.3
2015-02-24	440	17.00		0.12	0.05	0.130	6.32	3.5	19.0	19.2
2015-02-27	450	16.00		2.07	0.40	0.160	6.30	3.1	18.0	18.6
2015-03-03	440	19.00		1.44	0.05	0.210	6.38	3.2	22.0	22.3
2015-03-09		18.00		0.57	0.05	0.260	6.37	3.1	20.0	20.3
2015-03-12		17.00		0.31	0.34	1.200	6.16	2.9	19.0	20.5
2015-03-17		17.00		0.36	0.05	0.480	6.31	2.7	20.0	20.5
2015-03-26	320	15.00			0.05	0.110			19.0	19.2
2015-03-31	400	16.00		0.25	0.05	1.200	6.65	3.6	18.0	19.3
2015-04-06				4.23			6.60	10.4		
2015-04-08	430	15.00		0.22	1.90	2.700	6.50	5.1	19.0	23.6
2015-04-14	450	13.00	31	0.19	2.80	4.400	6.38	6.0	15.0	22.2
2015-04-21				0.25			6.47	7.7		
2015-04-28	750	10.00	63	0.09	1.20	0.500	6.57	8.5	14.0	15.7
2015-05-05	480	7.20	110	0.10	0.22	0.910	6.50	9.1	11.0	12.1
2015-05-12	390	6.10	170	0.67	0.05	0.750	6.82	15.5	8.9	9.7
2015-05-18	430	4.00	240	0.06	0.10	0.300	6.32	13.0	6.0	6.4
2015-05-26		2.10	220	0.12	0.05	0.580	6.41	14.0	4.2	4.8
2015-06-01	320		150	0.18	0.05	0.025	6.32	15.6	4.2	4.3
2015-06-04	370	1.30	190	0.08	0.05	1.200	6.35	15.3	3.4	4.7
2015-06-08	390	1.20	210	0.07	0.05	1.400	6.27	15.0	3.4	4.9
2015-06-16	450	1.40	260	0.24	0.05	1.500	6.36	16.4	2.8	4.4
2015-06-22	450	1.40	210	0.10	0.05	1.100	6.32	17.0	2.5	3.7
2015-07-01	420	1.20	180		0.05	0.025			2.4	2.5
2015-07-10	380	0.70	190	0.13	0.05	1.100	6.30	18.7	3.7	4.9
2015-07-14	400	0.87	240	0.04	0.05	1.100	6.31	19.5	2.4	3.6
2015-07-23	440	0.25	160	0.25	0.05	0.770	6.43	20.4	2.0	2.8
2015-07-30	460	0.25	140	0.04	0.05	0.600	6.36	20.8	1.9	2.5
2015-08-06	460	0.54	110		0.05	0.025			1.8	1.9
2015-08-12	470	0.46	120	0.04	0.81	0.260	6.37	21.7	1.9	3.0
2015-08-20	470	0.25	81	0.10	0.05	0.025	6.43	21.8	1.6	1.7
2015-08-26	450	0.66	74	0.19	0.05	0.076	6.24	22.4	1.4	1.5
2015-09-02	450	0.62	62	0.10	0.05	0.025	6.48	22.3	1.8	1.9
2015-09-09	460	0.74	60	0.19	0.14	0.025	6.33	22.2	1.9	2.1
2015-09-15	140	0.84	46	0.20	0.05	0.025	6.38	22.1	2.2	2.3
2015-09-23				0.12			6.40	21.4		
2015-09-29	450	1.20	27	0.05	0.22	0.025	6.42	20.5	2.3	2.5
2015-10-08	390		11	0.07	0.05	0.025	6.46	18.8	2.5	2.6
2015-10-24				0.06	0.05	0.025	6.53	18.0	2.2	2.3
2015-11-04			14	0.07	0.49	0.025	6.50	15.8	1.7	2.2
2015-11-12				0.11			6.38	15.2		
2015-11-17	360	0.77	14	0.08	0.05	0.083	6.50	14.5	1.6	1.7

DESIGN 1 - Raw Data

Saturated System Using Loamy Sand Nitrification Layer

Sample Date	Alkalinity	Ammonia	BOD5	DO	Nitrate	Nitrite	pH	Temp	TKN	TN
2015-12-02				0.15	0.78	0.091	6.52	12.2	1.6	2.5
2015-12-09	360			0.20	0.61	0.110	6.04	11.3	2.3	3.0
2015-12-15				0.13			5.99	11.4		
2015-12-21				0.12	0.43	0.025	6.27	11.7	1.8	2.3
2015-12-29				0.17			6.41	11.7		
2016-01-05	260		7	0.17	0.45	0.025	6.64	10.4	1.8	2.3
2016-01-12	330	0.49		0.24	1.90	0.025	6.28	9.0	2.2	4.1
2016-01-26	320	1.30		0.21	4.50	0.025	6.27	7.0	2.4	6.9
2016-02-02	320		5.2	0.27	3.10	0.025	6.54	6.5	3.4	6.5
2016-02-09	300		3.1	0.15	0.05	0.025	6.87	6.8	4.1	4.2
2016-02-16	290		4.8	0.16	3.80	0.026	6.36	5.9	5.0	8.8
2016-02-23	280	3.20	7	0.14	8.20	0.025	6.38	5.9	3.8	12.0
2016-03-02	290	3.20	5.1	0.11	5.40	0.025	7.03	6.4	4.3	9.7
2016-03-08		5.20		0.15	7.50	0.025	6.23	6.4	7.9	15.4
2016-03-15	310	3.70	6.9	0.86	8.10	0.025	5.93	7.0	4.3	12.4
2016-03-22				0.14			6.06	7.5		
2016-03-29				0.13			6.05	7.7		
2016-04-05	370	5.10	8.3	0.13	2.20	0.025	6.04	8.4	6.4	8.6
2016-04-12	370	4.90	5	0.19	1.80	0.025	5.96	8.2	6.0	7.8
2016-04-19	370	7.40	10	0.26	0.05	0.025	5.97	8.5	9.1	9.2
2016-04-26	420	7.50	10	0.18	1.30	0.025	5.96	9.4	9.6	10.9
2016-05-03	460	9.20		0.13	0.58	0.025	6.31	9.8	11.0	11.6
2016-05-10	450			0.14	0.38	0.025	6.20	10.1	13.0	13.4
2016-05-17		9.50	12	0.28	0.18	0.025	6.01	11.2	12.0	12.2
2016-05-24		9.80		0.24	0.05	0.025	6.49	12.3	13.0	13.1
2016-06-01		9.00	22	0.14	0.24	0.025	5.87	13.9	12.0	12.3
2016-06-07		9.20	20	0.12	0.32	0.025	5.57	14.8	14.0	14.3
2016-06-14		11.00	22	0.21	0.35	0.025	5.83	15.8	14.0	14.4
2016-06-21		9.40	13	0.27	1.30	0.025	5.94	16.7	15.0	16.3
2016-06-28		12.00		0.11	1.50	0.025	6.14	17.4	17.0	18.5
2016-07-06		13.00	10	0.14		0.025	5.88	18.5	17.0	18.0
2016-07-12		16.00	27	0.10	0.64	0.025	6.09	19.2	21.0	21.7
2016-07-18		13.00	5.3		3.30	0.025			20.0	23.3
2016-07-19		13.00	12	0.13	1.70	0.025	5.76	19.9	20.0	21.7
2016-07-20		16.00		0.05	0.94	0.025	5.84	20.1	21.0	22.0
2016-07-21		17.00			0.48	0.025			21.0	21.5
2016-07-26		14.00		0.25	0.76	0.025	5.98	21.2	21.0	21.8
2016-08-03		15.00	16	0.22	0.64	0.025	6.11	22.3	19.0	19.7
2016-08-09		13.00	9.3	0.13	0.05	0.025	5.91	21.9	16.0	16.1
2016-08-16		13.00	7.3	0.09	0.05	0.025	6.43	23.3	17.0	17.1
2016-08-22		7.20			2.30	0.025			15.0	17.3
2016-08-24		10.00	14	0.40	15.00	0.025	6.56	23.4	18.0	33.0
2016-08-25		7.10		1.48	48.00	0.310	6.73	26.8	15.0	63.3
2016-08-29				0.34			6.62	23.2		
2016-08-30		7.60	5.1	0.15	36.00	0.025	6.78	23.2	14.0	50.0
2016-09-07				0.20			6.52	22.5		
2016-09-12		2.20		0.05	13.00	0.025	6.77	22.3	3.6	16.6
2016-09-20				0.10			6.46	21.9		
2016-09-27				0.05			6.60	21.4		
2016-10-05		3.10	1	0.16	9.00	0.025	6.38	19.8	2.1	11.1
2016-10-13				0.22			6.37	18.5		

DESIGN 1 - Raw Data

Saturated System Using Loamy Sand Nitrification Layer

Sample Date	Alkalinity	Ammonia	BOD5	DO	Nitrate	Nitrite	pH	Temp	TKN	TN
2016-10-20				0.11			6.20	17.9		
2016-11-02		2.10	1	0.10	3.70	0.025	6.83	16.1	3.5	7.2
2016-11-08		2.80	1	0.18	5.70	0.025	6.19	15.2	2.8	8.5
2016-11-15		2.20	1	0.18	7.70	0.025	6.13	14.2	3.2	10.9
2016-11-28	250	2.70	1		2.60	0.025			4.0	6.6

Count	53	77	57	93	90	91	93	93	93	91
Average	396	7.36	64	0.27	2.44	0.280	6.32	13.9	8.9	11.7
Median	410	7.20	16	0.15	0.35	0.025	6.36	14.8	6.0	10.0
Std Dev	86	5.82	80	0.51	6.68	0.627	0.27	6.6	6.9	10.0
Confidence Interval	23	1.30	21	0.10	1.38	0.129	0.05	1.3	1.4	2.1
Upper CI	419	8.66	85	0.37	3.82	0.409	6.38	15.2	10.3	13.8
Lower CI	373	6.06	43	0.16	1.06	0.151	6.27	12.5	7.5	9.7

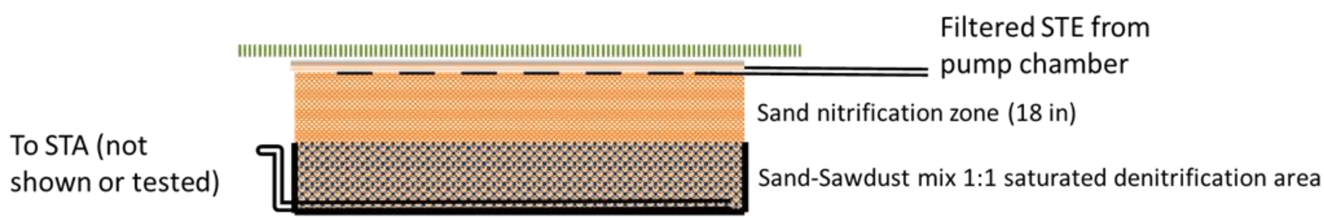
DESIGN 1 Lysimeter at interface of nitrification and denitrification layer - "PAN D"
RAW DATA

Sample Date	Alkalinit	Ammonia	BOD5	DO	Nitrat	Nitrite	pH	Temp	TKN	TN
2016-11-15		4.70		4.18	12.00	0.520	5.88	11.4	6.2	18.7
2016-11-08		0.50		2.72	15.00	0.650		13.0	1.1	16.8
2016-11-02		0.93		4.72	16.00	0.025		13.5	3.0	19.0
2016-10-20				3.24				17.7		
2016-10-13				3.26				16.9		
2016-10-05		0.92		2.45	21.00	0.025		18.6	2.4	23.4
2016-09-27				4.40			6.50	20.2		
2016-09-20				1.12			5.86	22.3		
2016-09-12		0.28			38.00	0.025			1.5	39.5
2016-09-07				1.94			6.17	22.8		
2016-08-30		0.19		5.15	55.00	0.025	6.96	24.8	1.1	56.1
2016-08-29				4.75			6.97	24.7		
2016-08-24		1.20			330.00	0.025			4.3	334.3
2016-08-03		0.72		5.28	300.00	0.025	6.22	23.1		300.0
2016-07-26		27.00			5.00	0.310			38.0	43.3
2016-07-21		16.00			0.32	0.880			21.0	22.2
2016-07-20		34.00		0.56	0.59	1.600	6.59	25.6	36.0	38.2
2016-07-19		27.00		1.41	0.05	0.270	6.59	29.1	39.0	39.3
2016-07-18		31.00			0.05	0.058			41.0	41.1
2016-03-29				3.22			6.24	8.2		
2016-03-15	260			5.58	2.60	0.025	6.14	7.1	20.0	22.6
2016-02-23	250			2.92	16.00	0.320	6.13	4.7	23.0	39.3
2016-02-09	250			3.14	18.00	0.200	6.65	3.9	17.0	35.2
2016-02-02	250			5.12	11.00	0.025	6.12	4.4	12.0	23.0
2016-01-26	270				13.00	0.460			9.4	22.9
2016-01-05	190	0.03			15.00	0.220				15.2
2015-12-02					23.00	0.110			0.9	24.0
2015-08-26				0.25			6.56	24.3		
2015-08-12		1.30		0.04	24.00	0.110	6.51	22.8	5.0	
2015-07-30				0.55	0.14	0.025	6.81	22.8		
2015-07-14		0.34		0.27	2.70	0.025	6.62	22.3	2.4	5.1
2015-07-10		0.70		0.12	0.75	0.110	6.66	21.2	4.3	5.2
2015-06-24					0.05	0.300				
2015-06-22				7.39			6.69	19.1		
2015-06-04		0.25		1.22			6.76	15.7	3.4	
2015-06-01		0.25		0.24	6.70	0.025	6.67	18.1	3.9	10.6
2015-05-26		0.39		0.07	0.83	0.060	6.80	16.1	4.8	5.7
2015-05-18	330	0.21		1.85	23.00	0.025	6.64	16.3	0.5	23.5
2015-04-28		0.71		0.70	58.00	0.930	6.67	9.1	1.0	59.9
2015-04-21				1.38			6.67	9.1		
2015-04-08	390	23.00			3.70	0.440			26.0	30.1
2015-01-16	350	0.40			0.30	0.025			1.8	2.1
Count	9	24		31	31	31	26	31	28	28
Average	282	7.2		2.56	32.64	0.254	6.50	17.1	11.8	47.0
Median	260	0.7		2.45	12.00	0.110	6.61	18.1	4.6	23.5
Std Dev	62	11.7		2.03	76.94	0.356	0.31	7.0	13.3	77.8
Confidence Interval	41	4.7		0.72	27.09	0.125	0.12	2.5	4.9	28.8
Upper CI	323	11.9		3.27	59.72	0.379	6.62	19.5	16.7	75.9
Lower CI	242	2.5		1.84	5.55	0.129	6.38	14.6	6.8	18.2

Appendix 3

Raw Data

DESIGN 2



DESIGN 2 Saturated system with sand as nitrification layer

Sample Date	Alkalinity	Ammonia	BOD5	DO	Nitrate	Nitrite	pH	Temp	TKN	TN	TSS
2017-01-04	160	0.53	1	0.52	7.6	0.025	6.05	7.57	1.2	8.8	23
2017-01-10				0.33			5.8	7.09			
2017-01-11	180	1.6	1		2.7	0.025			2.9	5.6	
2017-01-17	200	5.3		0.97	1.6	0.025	6.05	6.8	6.9	8.5	
2017-01-23		5.4	1	0.15	0.2	0.025	6.66	6.89	9.1	9.3	
2017-01-25		9	0	1.23	1.3	0.025	6.4	6.92	11	12.3	
2017-02-01				0.34			5.79	6.57			
2017-02-07		12	1	0.06	1.7	0.025	6.57	5.85	13	14.7	
2017-02-15				0.05			6.93	5.46			
2017-02-22		15	1	0.2	4.6	0.025	6.28	6	17	21.6	
2017-03-08		12	1	0.21	15	0.025	6.11	6.56	14	29.0	
2017-03-22				0.24			5.95	5.74			
2017-04-05		4.6		0.33	16	0.33	5.69	6.26	6.6	22.9	
2017-04-18				0.21			5.64	9.71			
2017-05-05		1.3	1	0.36	21	0.18	5.45	11.87	0.5	21.7	
2017-05-09		0.28		0.35	19	0.36	5.61	12.47	1.2	20.6	
2017-05-16		0.42		0.3	20	0.31	5.62	12.6	0.57	20.9	
2017-05-23					13	0.14			1.4	14.5	
2017-06-06				0.42			5.97	15.57			
2017-06-12		0.25		0.51	8.8	0.05	5.37	16.06	0.05	8.9	
2017-06-12		0.25			8.8					9.1	
2017-06-13		0.2			9.7	0.05			0.05	9.8	
2017-06-14				0.51			6.02	16.44			
2017-06-14	150	0.22		3.02	9.6	0.05	6.17	20.44	1.3	11.0	
2017-06-20				0.06			6.59	18.3			
Count	4	16	8	21	17	16	21	21	16	17	
Average	173	4.3	1	0.5	9.4	0.1	6.0	10.1	5.4	14.7	
Median	170	1.5	1	0.3	8.8	0.0	6.0	7.1	2.2	12.3	
Std Dev	22	5.1	0	0.6	6.9	0.1	0.4	4.8	5.7	6.8	
Confidence Interval	22	2.5	0	0.3	3.3	0.1	0.2	2.0	2.8	3.2	
Upper CI	194	6.8	1	0.8	12.7	0.2	6.2	12.1	8.2	17.9	
Lower CI	151	1.8	1	0.2	6.2	0.0	5.9	8.0	2.6	11.4	

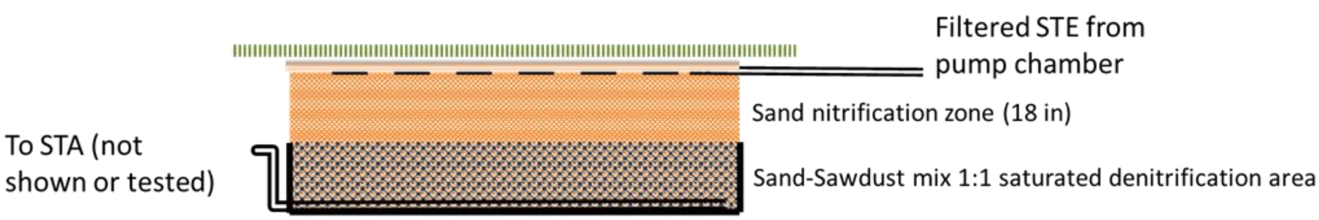
Pan D - Lysimeter at interface of the nitrification and denitrification layer

Sample Date	Alkalinity	Ammonia	BOD5	DO	Nitrate	Nitrite	pH	Temp	TKN	TN	TSS
2017-01-10							5.36	5.77			
2017-01-11					0.05	0.025			0.75	0.83	
2017-01-23		0.34		8.35	0.05	0.025	6.14	9.31	0.98	1.06	
2017-02-01				9.55			6.31	5.44			
2017-02-07				9.55	1.1	0.025	6.31	5.44	29	30.1	
2017-05-05				5.96	40	0.93	5.79	13.63	1	41.9	

Appendix 4

Raw Data

DESIGN 3



DESIGN 3 Saturated System Using Long Island - Sourced Materials

Sample Date	Alkalinity	Ammonia	BOD5	CBOD5	DO	Fecal coli	Nitrate	Nitrite	pH	Temp	TKN	TN
2016-09-19					0.09				6.58	24.2		
2016-09-27					0.05				6.68	23.0		
2016-10-05		1.60	92		0.11		2.20	0.025	6.43	20.0	33.2	35.4
2016-10-13		0.33	26		0.08		0.05	0.025	6.65	18.7	3.3	3.4
2016-10-20					0.08				6.57	17.8		
2016-10-25		0.41	28		0.13		0.05	0.025	6.51	16.9	2.3	2.4
2016-11-02		0.44	15		0.12		0.60	0.430	6.97	15.4	1.8	2.8
2016-11-08		0.48	12		0.19		2.80	0.025	6.29	14.4	1.6	4.4
2016-11-15		0.53	1		0.09		4.60	0.025	6.43	13.2	1.9	6.5
2016-11-21		0.77	5		0.08		5.40	0.025	6.35	12.8	2.0	7.4
2016-11-30		1.40	11		0.14		5.80	0.025	6.44	10.7	2.8	8.6
2016-12-05		1.10	1		0.12		7.00	0.025	6.51	10.7	3.1	10.1
2016-12-14					0.19				6.40	8.3		
2016-12-14		1.30	4		0.19		12.00	0.025	6.40	8.3	3.2	15.2
2016-12-21					0.30				6.11	6.8		
2016-12-21		1.00	4		0.30		10.00	0.400	6.11	6.8	2.5	12.9
2016-12-28		1.70	2		0.29		12.00	0.460	6.42	6.4	3.3	15.8
2017-01-04		0.03	1		7.70		4.30	0.025	5.59	11.2	0.3	4.6
2017-01-11		2.10	1		0.30		10.00	0.800	5.91	5.7	3.8	14.6
2017-01-17	140	2.00			0.92		35.00	0.025	6.10	5.9	3.8	38.8
2017-01-23		2.10	1		0.26		11.00	1.000	5.99	6.0	3.4	15.4
2017-01-25		1.50			0.28		13.00	1.000	6.29	6.2	4.0	18.0
2017-02-01					0.27				6.11	6.0		
2017-02-07		1.80	1		0.15		12.00	0.330	6.70	4.8	4.3	16.6
2017-02-15					0.02				6.86	4.7		
2017-02-22		1.80	11		0.23	9	11.00	0.240	6.05	4.4	3.8	15.0
2017-03-08		1.90	3		0.24	4	12.00	0.025	5.87	5.7	3.7	15.7
2017-03-22					0.25				6.00	4.8		
2017-04-05		0.83			0.23		6.60	0.380	6.01	5.9	2.2	9.2
2017-04-18					0.16				6.15	9.1		
2017-05-04		1.40		74	0.20		0.10	0.420	5.86	11.9	6.6	7.1
2017-05-09		0.43			0.28		0.05	0.025	6.07	12.3	28.0	28.1
2017-05-16		0.33		82	0.24		0.05	0.025	6.23	12.3	29.0	29.1
2017-05-23		0.05			0.22		0.20	0.025	6.36	13.9	2.7	2.9
2017-06-06		0.36	14	14	1.04		0.10	0.050	6.33	15.1	0.8	1.0
2017-06-12		0.26			1.12		0.05	0.050	5.87	16.1	0.6	0.7
2017-06-13		0.22					0.05	0.050			0.1	0.2
2017-06-14	220	0.40			0.40		0.05	0.050	6.50	16.3	0.9	1.0
2017-06-20	220	0.31		4.7	0.02		0.05	0.025	6.56	17.5	1.3	1.4
Count		30	19	4	38		30	30	38	38	30	30
Average		0.96	12	43.7	0.45		5.94	0.202	6.30	11.3	5.3	11.5
Median		0.80	4	44.0	0.21		4.45	0.025	6.34	11.0	3.0	8.9
Std Dev.		0.69	21	40.0	1.23		7.34	0.292	0.30	5.5	8.5	10.3
Conficence Interval		0.25	9	39.2	0.39		2.63	0.105	0.10	1.7	3.1	3.7
Upper CI		1.21	22	82.8	0.84		8.56	0.307	6.39	13.1	8.4	15.2
Lower CI		0.72	3	4.5	0.06		3.31	0.097	6.20	9.6	2.3	7.8

DESIGN 3 Lysimeter Sampling Ports Port 1 18" deep
Port 2 6" deep

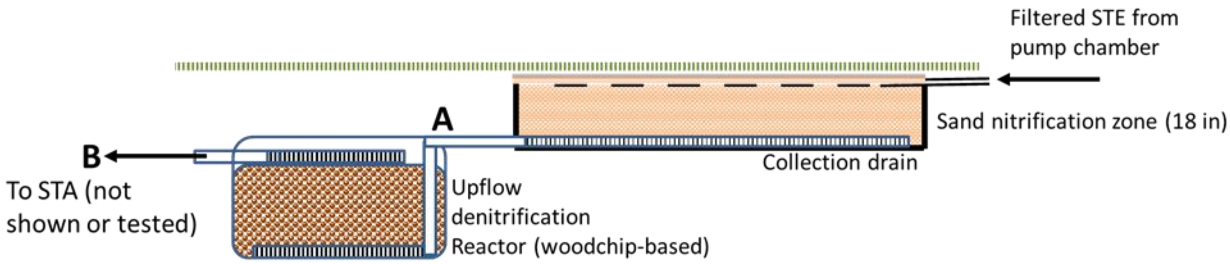
Sample Date	Sample Location	Ammonia	DO	Fecal coli	Nitrate	Nitrite	pH	Temp	TKN	TN
2016-09-27	Port 1	0.7			18	5.6			3.6	27.2
2016-10-05	Port 1	0.52	0.96		0.05	0.5	6.24	20	2	2.55
2016-10-13	Port 1	1.5	0.24		18	9.9	6.12	17.8	4.8	32.7
2016-10-20	Port 1		0.22				6.01	17.47		
2016-10-25	Port 1	0.4	1.36		35	5.3	5.83	16.65	2.2	42.5
2016-11-02	Port 1	0.14	1.06		40	2	6.27	14.36	2	44
2016-11-08	Port 1	0.11	1.15		42	2.2	6.06	13.44	1.5	45.7
2016-11-15	Port 1	0.61	1.23		39	1.7	5.67	11.95	2.4	43.1
2016-11-21	Port 1	0.12	1.43		40	0.52	5.63	12.14	1.5	42.02
2016-11-30	Port 1	2.8	1.78		18	0.025	6.06	9.43	5.4	23.425
2017-01-11	Port 1	2.6	6.73		21	1.5	5.73	4.56	4.2	26.7
2017-01-23	Port 1	0.43	3.8		37	1	5.45	5.47	1.6	39.6
2017-01-25	Port 1	0.42	4.04		23	0.71	5.57	5.77	2.6	26.31
2017-02-01	Port 1		4.88				5.5	5.11		
2017-02-07	Port 1	0.32	5.48		38	0.025	5.96	4.17	2	40.025
2017-02-15	Port 1		5.41				6.49	3.91		
2017-02-22	Port 1	0.08	5.08		34	0.054	5.45	4.54	1.5	35.554
2017-03-08	Port 1	4.3	5.08		35	0.025	5.45	4.54	1.5	36.525
2017-05-04	Port 1	0.38	3.29		39	0.077	5.53	12.46	1	40.077
2017-05-23	Port 1		2.13				6.09	14.67		
Count		16	19		16	16	19	19	16	16
Average		0.96	2.91		29.8	1.95	5.8	10.4	2.49	34.2
Median		0.43	2.13		35.0	0.86	5.8	12.0	2	38.1
Std Dev		1.22	2.12		12.0	2.74	0.3	5.6	1.31	11.0
Confidence Interval		0.60	0.95		5.9	1.34	0.1	2.5	0.64	5.4
Upper CI		1.56	3.87		35.7	3.29	6.0	13.0	3.13	39.7
Lower CI		0.37	1.96		24.0	0.60	5.7	7.9	1.85	28.8

Sample Date	Sample Location	Ammonia	DO	Fecal coli	Nitrate	Nitrite	pH	Temp	TKN	TN
2016-09-19	Port 2		3.85				6.92	24.17		
2016-09-27	Port 2	15			39	5.1			18	62.1
2016-10-05	Port 2	19	0.8		43	8.7	6.45	19.46	15	66.7
2016-10-13	Port 2	11	0.26		10	8.4	6.5	16.85	18	36.4
2016-10-20	Port 2		0.31				6.19	17.22		
2016-10-25	Port 2	5.5	1.14		9.1	24	5.94	16.27	8.5	41.6
2016-11-02	Port 2	8.7	1.81		8.3	18	6.56	13.42	11	37.3
2016-11-08	Port 2	6	1.21		9	20	5.96	12.42	6.6	35.6
2016-11-15	Port 2	4.5	1.9		11	21	5.78	10.86	7.5	39.5
2016-11-21	Port 2	4.2	0.8		16	18	6.45	11.31	5.8	39.8
2016-11-30	Port 2	13	4.15		8.3	4.9	6.21	8.45	15	28.2
2017-01-23	Port 2	12	2.77		16	2	5.89	5.69	15	33
2017-02-15	Port 2		4.15				6.68	3.45		
2017-02-22	Port 2	6.2	3.61	130	24	2.1	5.67	3.42	7.9	34
2017-03-08	Port 2	0.058	1.66	23	23	1.5	5.76	4.31	6.9	31.4
2017-05-04	Port 2	2.4	0.81		33	0.57	5.46	13.35	2	35.57
Count		13	15		13	13	15	15	13	13
Average		8.27	1.9		19.2	10.33	6.2	12.0	10.6	40.1
Median		6.20	1.7		16.0	8.40	6.2	12.4	8.5	36.4
Std Dev		5.43	1.4		12.3	8.59	0.4	6.2	5.1	11.4
Confidence Interval		2.95	0.7		6.7	4.67	0.2	3.1	2.8	6.2
Upper CI		11.23	2.7		25.9	15.00	6.4	15.2	13.3	46.3
Lower CI		5.32	1.2		12.5	5.66	5.9	8.9	7.8	33.9

Appendix 5

Raw Data

DESIGN 4



Sample Date	Alkalinity	Ammonia	CBOD	DO	Fecal coli	Nitrate	Nitrite	pH	Temp	TKN	TN	TP	TSS
2016-11-02		9.90	4	9.78	27	3.40	0.160	7.23	8.3	11.0	14.6		
2016-11-07		11.00				14.00	1.200			12.0	27.2		
2016-11-08	140	9.50	1	9.27	11	18.00	2.200	7.11	9.8	10.0	30.2		
2016-11-15	44	0.12	1	8.25	33	36.00	3.600	6.44	10.1	1.8	41.4		
2016-11-21		0.10	1	8.34	23	34.00	1.100	7.00	7.3	0.9	36.0		9
2016-11-30	42	0.16	1	9.16	33	36.00	0.600	6.42	10.7	1.4	38.0		
2016-12-05	53	0.25	1			34.00	0.480			0.8	35.3		
2016-12-14				11.98				6.37	7.3				
2016-12-20	41	0.57	1		33	30.00	0.340			1.3	31.6	2.9	24
2017-01-04	42	0.09	1	10.78	56	26.00	0.140	5.80	6.5	1.6	27.7	2.2	3
2017-01-10	40	0.14	1	10.78	7	29.00	0.025	6.31	5.6	1.2	30.2	2.4	4
2017-01-23		0.82	1	9.84		25.00	0.250	6.34	6.1	1.5	26.8	1.9	8
2017-01-24	48	0.89	5.5		5600	12.00	0.530			2.7	15.2	2.7	21
2017-01-25		0.28	2	0.61	1200	10.00	0.250	6.31	7.1	1.5	11.8	2.6	12
2017-01-27		0.08	1	8.66	20	16.00	0.025	6.22	6.4	1.5	17.5	2.2	9
2017-02-01		0.06	2.1	8.18	880	23.00	0.025	6.14	5.7	0.7	23.7	1.6	6
2017-02-07	40	0.32	1	10.03	11	28.00	0.025	6.62	4.7	1.0	29.0	1.8	5
2017-02-22		0.09	1	10.87	1	29.00	0.025	5.09	4.9	1.2	30.2	2.3	4
2017-03-07	30	0.03	1	10.88	5	27.00	0.025	5.70	5.4	0.3	27.3	2.3	1
2017-03-08				10.63	2000			5.77	5.3				
2017-03-15				12.54	3			5.93	4.2				
2017-03-21	16	0.67	1		15	29.00	0.025			1.8	30.8		4
2017-03-28	26	0.11	1	11.52	3	28.00	0.025	6.08	5.3	0.9	28.9	2.0	1
2017-04-04	40	0.10	1	10.61	140	13.00	0.290	5.88	5.7	0.8	14.1	2.2	12
2017-04-11	46	0.13	1	10.70	5	21.00	0.025	5.76	7.3	1.1	22.1	1.6	4
2017-04-19	40	0.32	1	11.20	1	29.00	0.025	5.93	9.9	1.0	30.0	2.1	4
2017-04-25	42	0.19	1	8.93	7	25.00	0.025	5.85	9.9	1.0	26.0	2.3	14
2017-05-09	67	0.15	1	8.66	20	15.00	0.025	5.95	12.0	1.9	16.9	1.9	9
2017-05-17	60	0.10	1	7.93	140	12.00	0.025	5.75	12.0	0.1	12.1	2.8	5
2017-05-25	53	0.05	1	9.74	12	20.00	0.025	6.32	14.0	1.7	21.7	2.5	2
2017-06-01	76	0.05	1		15	15.00	0.085			1.3	16.4	2.6	5
2017-06-07	76	0.10	1		360	17.00	0.025			0.9	17.9	2.8	18
2017-06-14	77	0.10	1	8.84	6	16.00	0.050	6.45	17.2	1.0	17.1	2.4	14
2017-06-21	64	0.05	1	7.11	27	5.00	0.140	6.64	18.5	0.6	5.7	2.6	19

Count	23	31	30	27	30	31	31	27	27	31	31	23	25
Average	52.3	1.178	1.32	9.475	28	21.79	0.38	6.2	8.4	2.14	24.3	2.3	9
Median	44	0.13	1	9.78		23	0.05	6.22	7.29	1.2	26.75	2.3	6
Std Dev	24.79	2.995	0.99	2.22		8.964	0.758	0.474	3.755	3.003	8.671	0.37	6.49
Confidence Interval	10.13	1.054	0.35	0.837		3.155	0.267	0.179	1.416	1.057	3.052	0.15	2.54
Upper CI	62.44	2.232	1.67	10.31		24.94	0.647	6.379	9.834	3.197	27.36	2.44	11.2
Lower CI	42.17	0.124	0.97	8.638		18.63	0.113	6.022	7.001	1.083	21.26	2.14	6.14

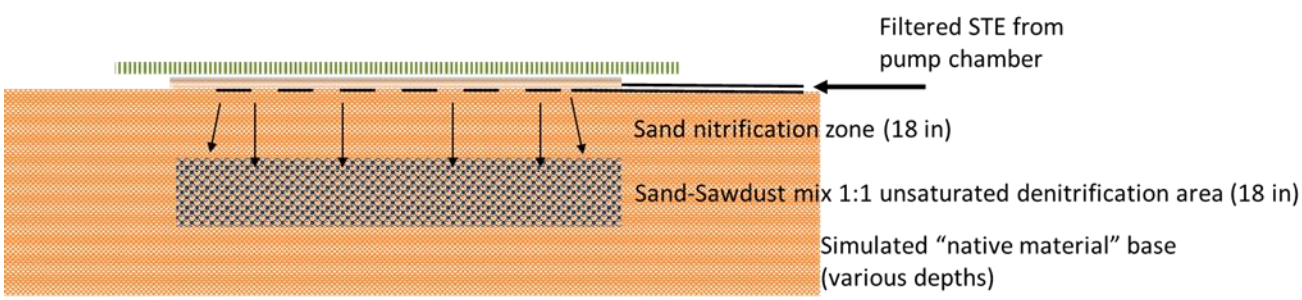
DESIGN 4 Final Discharge

Sample Date	Alkalinity	Ammonia	BOD	DO	Fecal coli	Nitrate	Nitrite	pH	Temp	TKN	TN	TSS
2016-10-25		0.77	590	2.23		0.05	4.500	5.52	15.59	4.5	9.05	
2016-11-02		2.10	640	7.24		0.05	0.025	5.36	8.53	6.2	6.275	
2016-11-08	100	5.40	510	6.04		0.05	1.400	5.39	11.05	9.8	11.25	
2016-11-15	110	0.20	250	5.74		0.05	0.025	6.08	12.58	3.4	3.475	
2016-11-21	120	0.11	210	3.76		0.05	0.025	6.14	14.62	1.8	1.875	
2016-11-30	120	0.30	1	4.81		0.05	0.025	6.48	12.71	2.5	2.575	
2016-12-05	140	0.25	73	5.68		0.05	0.025	6.57	10.07	3.1	3.175	
2016-12-14	130	0.09	94	8.75		0.05	0.025	6.54	6.11	1.8	1.875	
2016-12-21	130	0.25	28	6.50		0.05	0.025	7.08	11.36	5.3	5.375	
2016-12-28	140	0.11	1	6.65		0.20	0.025	6.77	10.82	1.8	2.025	
2017-01-04	130	0.07	66	5.35		0.05	0.025	6.25	4.61	1.4	1.475	
2017-01-11	120	0.18	44	6.49		2.60	0.510	6.74	5.37	2.3	5.41	
2017-01-17	110	0.15		7.27		0.05	0.025	6.75	9.88	1.5	1.575	
2017-01-23		0.07	25	7.28		9.40	0.025	6.94	5.34	1.6	11.025	
2017-01-25				6.56				6.64	4.86			
2017-01-27		0.17	23	7.52	110	0.05	0.025	6.72	6.17	1.8	1.875	
2017-02-01				7.50				6.40	4.32			
2017-02-07		0.18	52	8.02		0.05	0.025	7.06	4.28	1.3	1.375	
2017-02-15				8.46				7.09	3.62			
2017-02-22		0.10	27	8.00		0.05	0.025	6.68	6.09	1.0	1.045	
2017-03-08		0.12	8	7.10	1	0.05	0.025	6.60	9.36	1.4	1.475	
2017-03-21				7.81		0.16	0.097	6.18	3.75	1.4	1.657	
2017-03-30						1.80	0.025			1.4	3.225	
2017-04-05		0.18		7.84	66	2.00	0.280	6.58	12.87	0.1	2.33	
2017-04-18			19	5.65				6.78	13.12			10
2017-05-05		0.24	46	6.08		0.10	0.013	6.49	13.24	0.5	0.613	
2017-05-09		0.13	19	7.70		0.05	0.025	5.90	8.88	1.9	1.975	10
2017-05-16		0.20	24	0.55		0.05	0.025	6.93	17.79	1.9	1.975	
2017-05-23		0.05		4.06		0.05	0.025	6.95	18.78	1.0	1.025	
2017-06-06		0.16	19	6.16		0.10	0.170	5.29	10.07	0.1	0.37	
2017-06-14	140	0.05		4.06		0.05	0.050	7.32	23.57	1.6	1.7	
Count	12	25	22	30	3	27	27	30	30	27	27	2
Average	124.2	0.46	125.9	6.23	59.0	0.6	0.278	6.47	9.98	2.3	3.2	
Median	125.0	0.17	36.0	6.53	66.0	0.1	0.025	6.59	9.98	1.8	2.0	
Std Dev	13.114	1.11	196	1.858	54.836	1.875	0.888	0.54	4.96	2.1	3.0	
Confidence Interval	7.4	0.43	81.8	0.66	62.1	0.7	0.335	0.19	1.77	0.8	1.1	
Upper CI	132	0.90	208	6.89	121	1.3	0.613	6.67	11.75	3.1	4.3	
Lower CI	117	0.03	44	5.56	0	-0.1	-0.058	6.28	8.21	1.5	2.1	

Appendix 6

Raw Data

DESIGN 5



DESIGN 5 Pan Lysimeters beneath nitrifying area

Sample Date	Sample Locatio	Alkalinity	Ammonia	DO	Nitrate	Nitrite	pH	Temp	TKN	TN
2016-10-05	Port 1		0.28	0.13	13.00	0.025	6.37	21.37	1.0	14.0
2016-10-13	Port 1		0.63	0.33	0.05	0.440	6.28	19.40	6.0	6.5
2016-10-20	Port 1			0.72			6.26	18.82		
2016-10-25	Port 1		0.87	0.52	2.00	0.025	6.33	19.25	2.1	4.1
2016-11-02	Port 1		0.28	3.13	34.00	0.380	6.67	16.31	1.2	35.6
2016-11-08	Port 1		0.10	1.75	37.00	0.400	6.23	15.35	0.3	37.7
2016-11-15	Port 1		0.16	3.15	33.00	1.100	5.99	14.05	1.4	35.5
2016-11-21	Port 1		4.40	4.92	34.00	0.750	6.00	13.61	1.1	35.9
2016-11-30	Port 1		1.10	5.24	37.00	0.025	5.62	11.25	0.1	37.1
2017-01-11	Port 1		2.90	5.57	33.00	1.100	5.29	5.52	3.9	38.0
2017-01-17	Port 1		4.10	9.21	5.40	0.025	5.18	7.37	5.6	11.0
2017-01-23	Port 1		4.30	5.55	5.90	0.025	5.30	5.66	4.1	10.0
2017-02-15	Port 1			2.82			6.08	4.30		
2017-02-22	Port 1		4.30	3.17	27.00	0.025	4.92	4.20	5.7	32.7
2017-03-08	Port 1		4.20	4.42	29.00	0.025	5.35	5.69	7.7	36.7
2017-05-09	Port 1		0.07	2.70	30.00	0.025	5.29	13.21	1.4	31.4
2017-05-16	Port 1		0.07	2.11	13.00	0.025	5.75	13.58	0.6	13.6
2017-05-23	Port 1		0.05	0.80	12.00	0.160	6.22	15.36	1.0	13.2
2017-06-06	Port 1		0.49	1.17	13.00	0.050	5.89	16.34	1.0	14.0
2017-06-14	Port 1	29	0.33	2.50	16.00	0.050	5.49	17.70	1.1	17.2
2017-06-20	Port 1	32	0.25	0.76	11.00	0.025	5.61	19.38	1.2	12.2

Count			19	21	19	19	21	21	19	19
Average			1.52	2.89	20.28	0.246	5.82	13.22	2.4	23.0
Median			0.49	2.70	16.00	0.025	5.89	14.05	1.2	17.2
Std Dev			1.80	2.29	12.86	0.362	0.48	5.62	2.3	12.7
Confidence Interval			0.68	1.24	9.12	0.111	2.49	5.66	1.1	10.3
Upper CI			2.20	4.12	29.40	0.357	8.30	18.88	3.5	33.3
Lower CI			0.84	1.65	11.16	0.136	3.33	7.57	1.3	12.6
Sample Date	**Sample Locatio**	**Alkalinity**	**Ammonia**	**DO**	**Nitrate**	**Nitrite**	**pH**	**Temp**	**TKN**	**TN**
2017-05-04	Port 1a		0.69	4.10	28.00	0.092	5.19	14.32	1.0	29.1
2017-05-09	Port 1a		0.10	2.71	28.00	0.025	5.52	13.63	0.1	28.1
2017-05-16	Port 1a		0.09	0.61	18.00	0.080	6.07	13.67	1.8	19.9
2017-05-23	Port 1a		0.42	0.73	16.00	0.025	5.95	15.51	1.4	17.4
2017-06-06	Port 1a			0.44			6.22	16.08		
2017-06-14	Port 1a	60	1.40	0.56	12.00	0.050	5.77	17.78	1.9	14.0
2017-06-14	Port 1a	60	1.40	0.56	12.00	0.050	5.77	17.78	1.9	14.0
2017-06-20	Port 1a	58	1.10	0.81	12.00	0.025	5.83	19.48	1.8	13.8

Count			7	8	7	7	8	8	7	7
Average			0.74	1.32	18.00	0.050	5.79	16.03	1.4	19.5
Median			0.69	0.67	16.00	0.050	5.80	15.80	1.8	17.4
Std Dev			0.57	1.35	7.21	0.028	0.32	2.16	0.7	6.6
Confidence Interval			0.42	0.93	5.34	0.020	0.22	1.49	0.5	4.9
Upper CI			1.16	2.25	23.34	0.070	6.01	17.53	1.9	24.4
Lower CI			0.17	-0.03	10.79	0.022	5.47	13.87	0.7	12.8

DESIGN 5 Samples From Lysimeters 2 and 2A (beneath denitrification layer)

Sample Date	Sample Location	Alkalinity	Ammonia	DO	Nitrate	Nitrite	pH	Temp	TKN	TN
2016-10-05	Port 2		2.00	0.08	0.05	0.025	6.49	21.7	7.0	7.1
2016-10-13	Port 2		0.91	0.14	0.05	0.025	6.51	20.1	2.1	2.2
2016-10-20	Port 2			0.12			6.43	19.2		
2016-10-25	Port 2		1.20	0.01	0.05	0.025	6.49	19.1	7.3	7.4
2016-11-02	Port 2		0.66	0.27	0.05	0.760	6.69	17.1	3.3	4.1
2016-11-08	Port 2		0.99	0.21	0.05	0.025	6.41	16.1	2.1	2.2
2016-11-15	Port 2		0.47	0.28	0.05	0.025	6.31	14.8	2.8	2.9
2016-11-21	Port 2		0.47	0.26	1.90	0.025	6.25	13.9	1.7	3.6
2016-11-30	Port 2		0.78	0.2	0.05	0.025	6.24	12.1	3.1	3.2
2017-01-11	Port 2		0.50	5.04	3.70	0.240	5.99	5.9	2.6	6.5
2017-01-23	Port 2		1.20	5.12	4.90	0.025	6.15	6.1	2.9	7.8
2017-01-25	Port 2		1.10	4.99	3.80	0.025	6.17	6.1	3.1	6.9
2017-02-01	Port 2			4.31			6.03	6.2		
2017-02-07	Port 2		1.20	4.94	5.40	1.800	6.5	5.3	2.6	9.8
2017-02-15	Port 2			3.08			6.76	4.9		
2017-02-22	Port 2		0.96	3.32	9.20	0.025	5.65	4.5	2.1	11.3
2017-03-08	Port 2		1.20	4.72	4.30	0.025	5.82	6.2	3.2	7.5
2017-03-22	Port 2		0.88	0.75	8.20	0.025	5.73	6.2	2.3	10.5
2017-04-05	Port 2		0.79	0.75	13.00	0.350	5.73	6.2	2.5	15.9
2017-04-18	Port 2		1.40	0.51	9.30	0.610	5.83	9.0	2.8	12.7
2017-05-04	Port 2		0.57	0.76	0.56	0.011	5.76	12.2	2.7	3.3
2017-05-09	Port 2		0.26	0.44	5.00	0.640	5.75	12.9	2.5	8.1
2017-05-16	Port 2		0.27	0.35	0.32	0.025	6.03	13.2	2.3	2.6
2017-06-06	Port 2		0.56	0.22	0.10	0.083	6.03	16.1	0.2	0.3
2017-06-14	Port 2	200	0.69	0.28	0.05	0.050	6.34	16.9	1.6	1.7
2017-06-20	Port 2	190	0.58	0.09	0.05	0.025	6.31	18.5	1.3	1.4
Count			23	26	23	23	26	26	23	23
Average			0.85	1.59	3.05	0.213	6.17	11.9	2.8	6.0
Median			0.79	0.40	0.56	0.025	6.21	12.5	2.6	6.5
Std Dev			0.41	2.00	3.83	0.413	0.32	5.7	1.5	4.1
Confidence Interval			0.17	0.77	1.56	0.169	0.12	2.2	0.6	1.7
Upper CI			1.02	2.35	4.61	0.382	6.29	14.1	3.4	7.7
Lower CI			0.45	-0.41	-0.78	-0.200	5.85	6.3	1.2	2.0
Sample Date	**Sample Location**	**Alkalinity**	**Ammonia**	**DO**	**Nitrate**	**Nitrite**	**pH**	**Temp**	**TKN**	**TN**
2017-03-22	Port 2a		0.48	2.36	19.00	0.025	5.71	5.2	1.9	20.9
2017-04-05	Port 2a		0.25	1.33	23.00	0.420	5.62	6.2	1.2	24.6
2017-04-18	Port 2a		0.51	0.83	18.00	0.930	5.67	9.0	1.8	20.7
2017-05-04	Port 2a		0.03	0.46	8.60	0.180	5.59	12.1	1.0	9.8
2017-05-09	Port 2a		0.13	0.39	0.05	0.002	5.73	12.8	1.9	2.0
2017-05-16	Port 2a		0.44	0.36	0.05	0.025	6.08	13.2	1.6	1.7
2017-06-06	Port 2a		0.97	0.36	0.10	0.050	6.05	15.6	2.2	2.4
2017-06-14	Port 2a	220	1.00	0.25	0.05	0.050	6.30	16.5	1.5	1.6
2017-06-20	Port 2a	190	0.92	0.04	0.05	0.025	6.31	18.5	1.8	1.9
Count			9	9	9	9	9	9	9	9
Average			0.53	0.71	7.66	0.19	5.90	12.1	1.7	9.5
Median			0.48	0.39	0.10	0.05	5.73	12.8	1.8	2.4
Std Dev			0.37	0.72	9.75	0.31	0.29	4.6	0.4	9.8
Confidence Interval			0.24	0.47	6.37	0.20	0.19	3.0	0.2	6.4
Upper CI			0.76	1.18	14.03	0.39	6.09	15.1	1.9	15.9
Lower CI			0.16	-0.01	-2.09	-0.12	5.61	7.6	1.3	-0.3

DESIGN 5 Sump (Final Discharge)

Sample Date	Alkalinity	Ammonia	CBOD5	DO	Nitrate	Nitrite	pH	Temp	TKN	TN
2016-10-05		0.03	1	0.10	0.05	0.025	5.73	19.5	0.1	0.2
2016-10-13		0.03	1	0.38	4.00	0.025	5.46	19.2	1.3	5.3
2016-10-20				0.43			5.38	18.7		
2016-10-25		0.03	1	0.47	2.70	0.025	5.53	18.4	0.7	3.4
2016-11-02		0.03	1	0.67	2.60	0.025	6.69	18.1	1.0	3.6
2016-11-08		0.03	1	1.42	6.40	0.025	6.52	17.5	0.9	7.3
2016-11-15		0.07	1	2.23	8.20	0.220	5.99	17.6	1.2	9.6
2016-11-21		0.42	1	2.24	8.60	0.460	6.04	16.8	1.0	10.1
2016-11-30		0.10	1	2.48	9.60	0.025	6.16	15.6	0.1	9.7
2016-12-05		0.25	1	2.54	9.60	0.025	6.13	15.2	0.8	10.4
2016-12-14		0.17	1	3.52	16.00	0.025	6.14	13.6	1.1	17.1
2016-12-21				3.00			6.40	13.2		
2016-12-28		0.03	1	2.46	12.00	0.440	6.25	11.7	0.8	13.2
2017-01-04		0.03	1	4.07	13.00	0.025	6.08	11.5	0.6	13.6
2017-01-11				4.78			6.23	11.3		
2017-01-17	130	0.03		8.30	9.60	0.330	6.27	9.4	0.9	10.8
2017-01-23		0.03		2.86	10.00	0.025	6.25	9.6	0.3	10.3
2017-01-25		0.07		5.29	11.00	0.025	6.25	8.9	0.5	11.6
2017-02-01				4.16			6.08	8.8		
2017-02-07		0.24	1	2.88	12.00	0.025	6.42	8.9	0.9	12.9
2017-02-15				5.38			6.50	9.2		
2017-02-22		0.10	1	5.88	7.00	0.025	6.04	8.6	0.5	7.5
2017-03-08		0.15		4.72	12.00	0.025	5.91	6.2	0.7	12.8
2017-03-22		0.20		3.90	13.00	0.025	5.88	7.8	0.6	13.6
2017-04-05		0.08		5.60	8.30	0.025	5.59	7.2	0.4	8.8
2017-04-18		0.03		5.24	10.00	0.025	5.67	8.2	0.6	10.6
2017-05-04		0.14	1	4.43	15.00	0.026	5.21	9.5	0.5	15.5
2017-05-09		0.07		4.33	10.00	0.025	4.99	10.0	0.8	10.8
2017-05-16		0.07		0.61	9.40	0.063	5.99	13.7	0.1	9.5
2017-05-23		0.05		2.93	10.00	0.025	5.79	11.3	0.1	10.2
2017-06-06		2.00	2	1.62	4.40	0.100	5.86	12.4	0.1	4.6
2017-06-14	120	0.16		2.13	4.00	0.050	6.02	13.0	0.7	4.7
2017-06-20	120	0.05	1	0.88	3.70	0.025	6.09	13.4	0.3	4.0

Count		28	17	33	28	28	33	33	28	28
Average		0.17	1.06	3.09	8.65	0.08	5.99	12.53	0.62	9.34
Median		0.07	1.00	2.88	9.60	0.03	6.04	11.66	0.63	10.11
Std Dev		0.37	0.24	1.96	3.95	0.12	0.38	3.96	0.35	4.02
Confidence Interval		0.14	0.12	0.67	1.46	0.05	0.13	1.35	0.13	1.49
Upper CI		0.30	1.17	3.76	10.11	0.12	6.12	13.88	0.75	10.83
Lower CI		0.03	0.94	2.42	7.18	0.03	5.86	11.18	0.49	7.85